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International Correspondence Schools, Scranton, Pa.

ALTERNATING CURRENTS
ELECTRIC TRANSMISSION
ELECTRIC LIGHTING

SCRANTON
INTERNATIONAL TEXTBOOK COMPANY

PRINTED IN THE UNITED STATES.

BURR PRINTING HOUSE
FRANKFORT AND JACOB STREETS
NEW YORK

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CONTENTS

ALTERNATING CURRENTS.

(PART 1.)

REPRESENTATION OF ALTERNATING CURRENTS.

1. So far all the problems we have considered in connection with electric currents have dealt with *direct currents.* In connection with the theory of the dynamo, it was shown that when a simple loop was revolved in a magnetic field so as to cut across the lines of force, a current was generated that flowed first in one direction and then in the other; in other words, an *alternating current* was generated. In order to change this alternating current to a direct current, the commutator is added.

2. In taking up the applications of electricity we have to deal with both direct and alternating currents. The latter have, in recent years, become of great importance because the alternating current has displaced the direct current for many lines of work, especially in the field of electric-power transmission. It is necessary to consider alternating currents by themselves, because, by reason of the fact that an alternating current is continually changing both its amount and the direction of its flow, its behavior is, in many cases, quite different from that of a direct current. The apparatus used in connection with alternating-current installations is, in general, different from that which has

been described as used in connection with direct-current outfits and needs to be considered separately. Moreover,

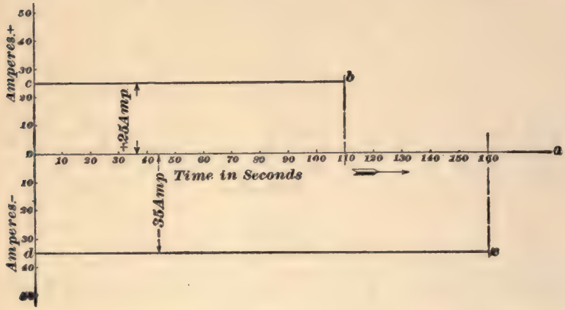


FIG. 1.

on account of the nature of alternating currents, they do not flow in accordance with the simple laws that govern the flow of direct currents.

3. In order to study the action of alternating currents, it is absolutely necessary that there be some means of representing them on paper by means of diagrams; consequently, before going on with the study of alternating-current apparatus, it is necessary to get these methods of representation firmly fixed in mind.

4. The current furnished by an ordinary direct-current dynamo having a fairly large number of commutator bars is practically continuous; i. e., the current does not fluctuate to any extent as the armature revolves and, of course, never reverses its direction of flow. In continuous-current circuits, the current flows uniformly in one direction; in other words, as time elapses the value of the current does not change. This condition might be represented graphically as shown in Fig. 1. Time is measured along the horizontal line $0\,a$, and as the current remains at the same value, it might be represented by the heavy line $c\,b$; the height of

this line *above* the horizontal would indicate the value of the current, i. e., +25 amperes. A current of −35 amperes, i. e., a current flowing in the opposite direction, would be represented by the heavy line *d e below* the horizontal. Time is laid off to scale (in this case each division represents 10 seconds), so that the farther we go from *0* in the direction of the arrow, the greater is the length of time that has elapsed. The line *c b* represents a current of 25 amperes, flowing uniformly in the positive direction for 110 seconds, and *d e* a current of 35 amperes flowing uniformly in the reverse direction for 160 seconds.

5. In the case of alternating currents, the direction of the flow is continually changing. This may be shown graphically, as in Fig. 2. In this case a current of 25 amperes flows for an interval of 1 second in the positive direction; it then reverses, flows for a similar interval in the opposite direction, and again reverses. This operation is repeated

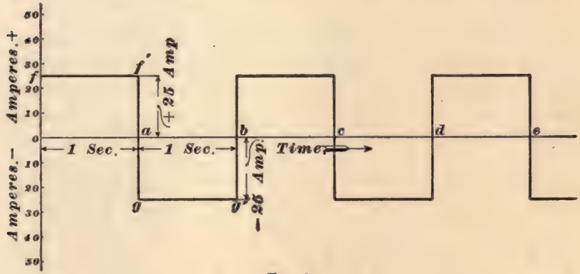


FIG. 2.

at regular intervals, as shown by the line, and any current that passes repeatedly through a set of values in equal intervals of time, such as that shown above, is known as an **alternating current.** The line *0 f f' a g g' b* is often spoken of as a **current,** or **E. M. F., wave,** depending on whether the diagram is used to represent the current flowing in a circuit or the E. M. F. that is setting up the current. The positive half wave *0 f f' a* is of almost exactly the same

shape as the negative half wave $a g g' b$ in most practical cases. Induction coils produce E. M. F.'s that have different positive and negative half waves, but in the case of E. M. F.'s produced by alternating-current dynamos, the two waves are almost identical.

6. The outline of the alternating-current waves usually met in practice is always more or less irregular, the shape of the wave depending largely on the construction of

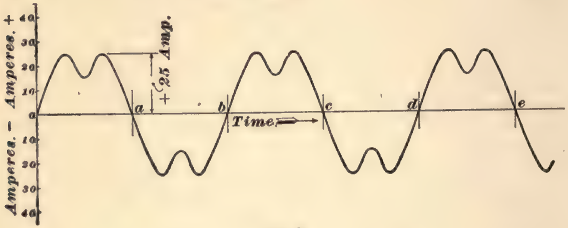


FIG. 3.

the machine producing it. Some of the more common shapes are shown in Figs. 3, 4, 5, and 6. Figs. 3, 4, and 5 show the general shape of the waves produced by some machines used for lighting work and having toothed armatures. The student should notice that while the waves are

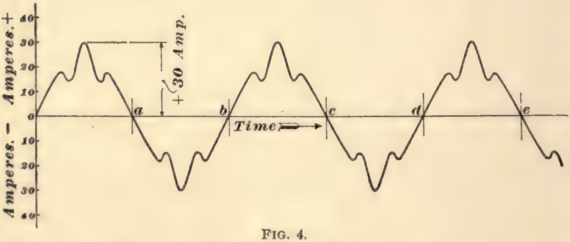


FIG. 4.

irregular, the same set of values are repeated over and over, and that the set of negative values of the current is the same as the positive, thus producing a symmetrical curve

with reference to the horizontal line. Fig. 6 represents a form of wave that is commonly met, especially in the case of

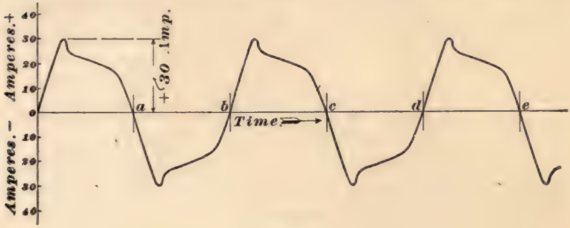


FIG. 5.

large alternators designed for power transmission. It will be noticed that this curve is practically symmetrical as

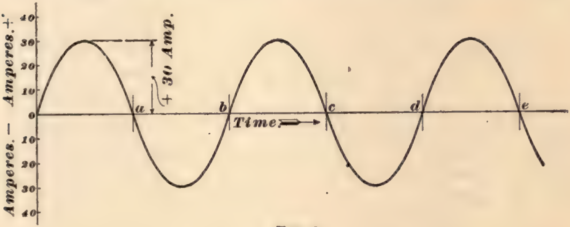


FIG. 6.

regards both the horizontal line $0\ a\ b\ c$ and a vertical passing through the highest point of the curve.

CYCLE, FREQUENCY, AND ALTERNATION.

7. In the curves shown in Figs. 3 to 6, the current passes through a set of positive values while the interval of time, represented by the distance $0\,a$, is elapsing, and through a similar negative set during the interval represented by the distance $a\,b$. This operation of passing through a complete set of positive and negative values is repeated over and over in equal intervals of time.

The complete set of values that an alternating current passes through repeatedly as time elapses is called a **cycle.** A cycle would, therefore, be represented by the set of values that the current passes through while the time represented by the distance $0\,b$ was passing.

8. *The number of cycles passed through in a given interval of time (usually one second) is called the* **frequency** *of the current.* For example, if the current had a frequency of 30, it would mean that it passed through 30 complete cycles, or sets of values, per second. In this case, the distance $0\,b$ would, therefore, represent an interval of $\frac{1}{30}$ second, and the time occupied for each half wave, or the distance $0\,a$, would be $\frac{1}{60}$ second. The frequency is usually denoted by the letters n or f, although the symbol $\sim$ is sometimes used. Frequencies used in alternating-current work vary greatly and depend largely on the use to which the current is to be put. For lighting work, frequencies from 60 to 125 or 130 are in common use. For power-transmission purposes, the frequencies are usually lower, varying from 60 down to 25, or even less. Very low frequencies cannot be used for lighting work because of the flickering of the lamps. Several of the large companies have adopted 60 as a standard frequency for both lighting and power apparatus. This is well suited for operating both lights and motors and enables both to be run from the same machine—a considerable advantage, especially in small stations. The high frequencies of 125–130 are going out of use except in stations that operate lights exclusively. When the current is used exclusively for power transmission, low frequencies of 25 or 40 are common.

9. An **alternation** is half a cycle. It is, therefore, represented by one of the half waves, and there are two alternations for every cycle.

Instead of expressing the frequency of an alternator as so many *cycles per second*, some prefer to give it in terms of so many *alternations per minute.* For example, suppose we have an alternator (alternating-current dynamo) supplying current at a frequency of 60, i. e., 60 complete cycles per

second, or 3,600 per minute. Since there are two alternations for every cycle, the machine might be said to give 7,200 *alternations per minute.* The method of expressing the frequency as so many cycles per second is, however, the one most commonly used.

PHASE DIFFERENCE.

10. Currents in Phase.—Two or more alternating currents that have the same frequency are said to be **in phase** when they come to their maximum values at the same instant and pass through zero at the same instant. In other words, the two waves vary in unison with each other, as shown in Fig. 7. Here we have two currents A and B, one having a maximum value of 5 amperes and the other a maximum

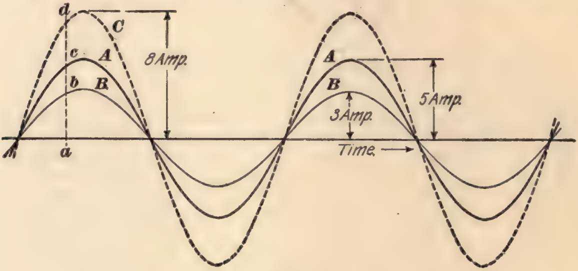


FIG. 7.

value of 3 amperes, in phase, or in step, with each other. The currents must, of course, have the same frequency, but the point to be noted is that both curves cross the horizontal line at the same points or the currents pass through zero at the same instant. Also both curves reach their maximum values at the same instant. The above two curves are shown as referring particularly to currents, but the same holds true with regard to two E. M. F's.

11. Currents Out of Phase.—Two or more currents of the same frequency are said to be **out of phase** when

they do not reach their maximum values at the same instant. This will be understood by referring to Fig. 8, where the two currents represented by the curves A and B are out of phase with each other. These curves are exactly the same as those given in the last figure. They are of the same frequency, but curve A is displaced from B along the axis by the distance $a\ b$, with the result that the two curves do not cross the axis together nor reach their maximum values together. In other words, at the instant c, say, when current A is zero, current B is not zero but has a value represented

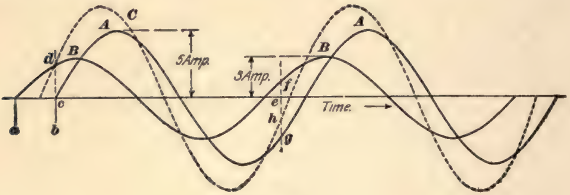


FIG. 8.

by the vertical line $c\ d$. Now time is supposed to be measured along the horizontal line in the direction of the arrow, so that the point c represents a *later* instant than the point a, that is, curve A does not start until curve B has already reached the value represented by $c\ d$. The curve A is, therefore, said to **lag** behind the curve B, and the current represented by A is lagging behind the current represented by B. Sometimes the same thing is expressed by saying that the current B **leads** the current A.

12. Synchronism.—Strictly speaking, two alternating currents are in synchronism when they have the same frequency; but the term **in synchronism,** as applied to either alternating currents or E. M. F.'s, implies that the two currents or E. M. F's are not only of the same frequency but are also in phase. For example, the two currents in Fig. 7 are in synchronism. One alternator is said to be in synchronism with another when its frequency is the same and when

it is also in phase with the other. The word synchronism means the state of being synchronous or occurring at the same time.

In Figs. 7 and 8, the curves were both taken to represent alternating currents, but in alternating-current circuits there are cases where the current lags behind the E. M. F.; so that in Fig. 8 the curve *A* might represent a lagging current and the curve *B* the E. M. F. driving the current through the circuit. Also, under certain conditions, the E. M. F. may be behind the current, so that curve *B* might represent the current and curve *A* the E. M. F. It is this difference in phase that may occur between currents and E. M. F.'s that is accountable for many of the differences in behavior of alternating currents as compared with direct currents. The causes that bring about this phase difference will be studied later.

ADDITION OF ELECTROMOTIVE FORCES AND CURRENTS.

13. In Fig. 7 the student should note that where the two currents are in phase, they always flow in the same direction with relation to each other. For example, when current *A* is flowing in the positive direction, so also is current *B*; and

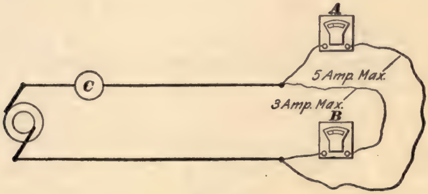


FIG. 9.

when current *A* is flowing in the negative direction, so is current *B*. The result is that the total current, as represented by the sum of the two currents, is obtained by adding the two together; that is, the two currents whose maximum values are 5 and 3 amperes give a total current whose maximum

value is 8 amperes. The combined current would be represented by the dotted line. Points on this dotted curve are obtained by adding the values of the other two curves. For example, the vertical line $a\,d$ is equal to $a\,c + a\,b$. The maximum value of the curve representing the sum of the currents is $5 + 3 = 8$ amperes, and the dotted curve is in phase with the other two. Suppose, then, that we have an alternator A, Fig. 9, feeding two circuits A and B. The current in A has a maximum value of 5 amperes and that in B of 3 amperes. The ampere meter C would then indicate a current having a maximum of 8 amperes. In other words, *when the currents in A and B are in phase*, the ammeter C will give a reading equal to the sum of the readings given by A and B, just as would be the case with a direct current.

14. Now consider Fig. 8, where the currents A and B are not in phase. It is easy to see that at certain portions of the cycle the two currents are opposing each other, as at the point e, where current B has the value $e\,f$ in the positive direction, and current A a value $e\,g$ in the negative direction. The resultant current will then be the difference between the two, or $e\,h$, because $e\,h$ is equal to $e\,g$ less $e\,f$. We can obtain the dotted curve C, which represents the sum of the other two, by obtaining a number of points like h. Note particularly that the maximum value of this dotted curve is not 8 amperes, as in the last case, but is considerably less. Also note that the dotted curve is not in phase with either of the other two. If, therefore, we had an alternator feeding two circuits, as shown in Fig. 9, and if the currents in A and B were *out of phase* with each other, the reading given by ammeter C would be *less* than the sum of the readings given by A and B, and the main current furnished by the alternator would be out of phase with the currents in A and B. It is easily seen from Fig. 8 that where the currents are out of phase there are times when they oppose each other, so that it is only natural to expect that the resultant current will be less in Fig. 8 than in Fig. 7.

15. To summarize the foregoing we may state that:

1. *Two alternating currents or E. M. F.'s that are* **in phase** *with each other may be added in the same way as direct currents or E. M. F.'s.*

2. *If two alternating currents that are* **in phase** *be added together, the resultant current or E. M. F. is also in phase with the original currents or E. M. F.'s.*

3. *If two alternating currents or E. M. F.'s that are* **out of phase** *be added together, the resultant current or E. M. F. will be less than the sum of the two, and this resultant current or E. M. F. will be out of phase with the original currents or E. M. F.'s.*

16. In referring to the phase difference between two curves, it is customary to express the phase difference as so many degrees. For example, a complete cycle from *a* to *c*, Fig. 10, is taken as 360°; a half cycle, or alternation, will be 180°; and a quarter cycle, 90°. In Fig. 10, the curve *B*

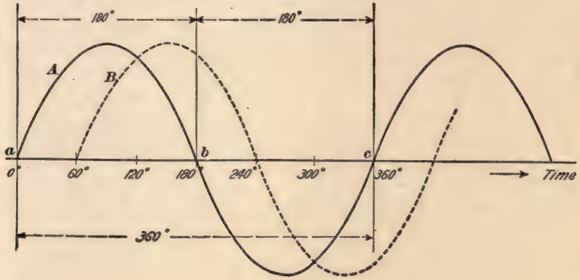


FIG. 10.

would be spoken of as lagging 60° behind *A*, because it does not start in until $\frac{1}{6}$ cycle has elapsed after *A* has started. This amount of lag, expressed in degrees, is called the **angle of lag**. If the angle of lag were zero, the two curves, Fig. 10, would be in phase.

17. Two-Phase System.—If two currents differ in phase by 90°, they are said to be at **right angles** to each other, or in **quadrature.** In Fig. 11, suppose that we have two alternators *A* and *B*, with their armatures mounted on the same shaft and feeding two separate circuits *1*, *2*.

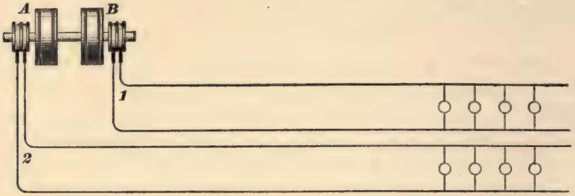


FIG. 11.

Also, suppose that the armatures are so mounted that just at the instant the current in circuit *1* is at its maximum value, the current in *2* is passing through its zero value. The curves representing the currents would then be as shown in Fig. 12. These two currents differ by 90°, or are in

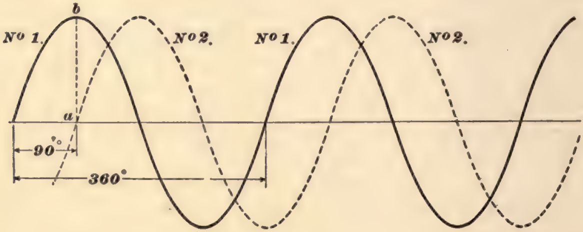


FIG. 12.

quadrature, or at right angles to each other. Under such circumstances it is easily seen that when No. *1* is at its maximum value *a b*, No. *2* is passing through its zero value, and *vice versa*. The system shown in Fig. 11 constitutes what is called a **two-phase** system.

A **two-phase system** *is, therefore, one in which two simple*

alternating currents are used, these two currents differing in phase by 90°, or one-quarter of a cycle.

Two currents differing in phase, as above, are usually called a two-phase current, although the use of the term two phase implies that more than one current is used. What is meant is that there are two simple currents differing in phase by 90°, or one-quarter of a cycle.

18. In practice it would not be necessary to use two armatures, as shown in Fig. 11, in order to generate two currents displaced in phase by 90°, although this has been done in some cases. By providing a single armature with two groups of windings properly disposed with regard to each other, the same result may be obtained. This will be explained later in connection with alternators.

19. Usually a two-phase system uses four wires, as shown in Fig. 11, although this is not absolutely necessary. If the central wire is made large enough, it can be made to answer as the return wire for both the others, as indicated in Fig. 13. Here C is the common return wire. The current that will flow in C may be obtained by adding the curves shown in

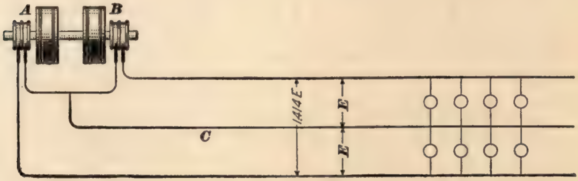


Fig. 13.

Fig. 12; and as these two curves differ so much in phase, it is at once apparent that the current in C will not be twice the current in the outside wires. As a matter of fact, the current in the middle wire will be 1.414 times the current in the outside wires. Also, if E is the voltage between the middle and either outside wire, the voltage between the two

outside wires will be 1.414 E. It is best, however, to have the two sides of the system independent, and for this reason the four wires are generally used.

20. Three-Phase System.—*A* **three-phase system** *is one that uses three alternating currents that differ in phase by 120°, or one-third of a complete cycle.*

In Fig. 14 we have three alternator armatures mounted on the same shaft and supplying current to three circuits A, B, and C. The armatures are so fixed on the shaft with regard to each other that the E. M. F. in B lags 120°, or one-third of a cycle, behind A. The current in C lags a similar amount behind B, and the current in A lags 120° behind C. In Fig. 15, if we represent the current in A by the full-line curve, then the dotted curve lagging 120°, or one-third cycle, behind will represent the current in B. The current in C will be represented by the dot-and-dash curve

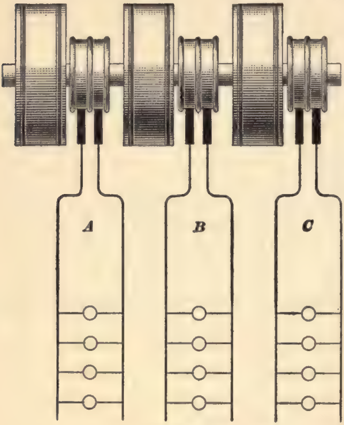


FIG. 14.

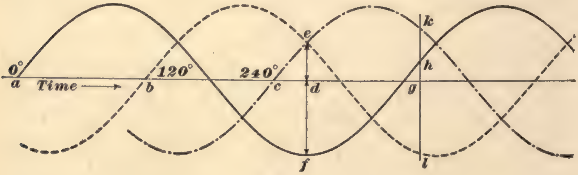


FIG. 15.

120° behind the dotted curve. The distances *a b* or *b c* are equivalent to 120° because they are equal to one-third of the distance representing a whole cycle, or 360°.

We have here three distinct alternating currents that differ in phase by 120°, and this constitutes a *three-phase system.* As in the two-phase system, these three currents, or rather the E. M. F.'s that set up the currents, can be generated by a single armature provided with three properly disposed windings. Also, we might use one wire *D* as a common return for the other three, as shown in Fig. 16.

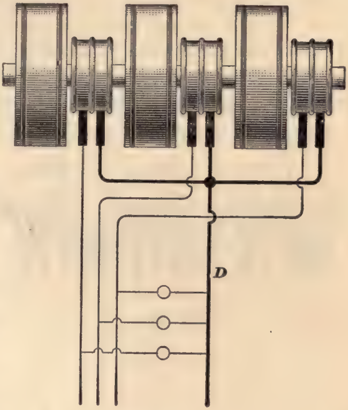


FIG. 16.

21. The current in the common return wire will be the sum of the three currents indicated by the curves shown in Fig. 15. Now, in Fig. 15 the curves are all of the same height; or, in other words, the currents in each of the three phases are supposed to be equal, or the system **balanced.** Under these circumstances the three curves exhibit a peculiarity that is taken advantage of to do away with the common return wire *D*. In Fig. 15 take any point *g* and draw a vertical line cutting the three curves. If these three lines are measured, it will be found that $gl = gh + gk$. This means that the current that tends to flow in the positive direction is just neutralized by the current tending to flow in the negative direction; at the point *d* the current in phase *A* is at its maximum negative value, while the currents in the other two phases are each one-half as great and

in the positive direction, or $df = 2\,de$. This holds good for any points that may be taken, and the result is that the sum of the currents is always zero. Such being the case, there is no need of providing any wire for the return current and the system may be operated with three wires, as shown in Fig. 17. Under these circumstances each wire acts successively as the return wire for the other two. It must be remembered, however, that the sum of the three curves, Fig. 15, is zero only when the load is the same on all three phases. It is easily seen that if one curve is higher than the others, there will be a current in the return wire, and this wire should be provided wherever the system is liable to become unbalanced. In most cases that arise in practice, the load can be kept sufficiently near a balanced condition to render the fourth wire unnecessary, and three wires are nearly always used for the operation of three-phase systems. Where a single armature is used, as is always done in practice, the connections between *a*, *b*, and *c*, Fig. 17, are, of course, made inside the armature, thus reducing the number of necessary collecting rings to three. This will be explained more fully in connection with alternators.

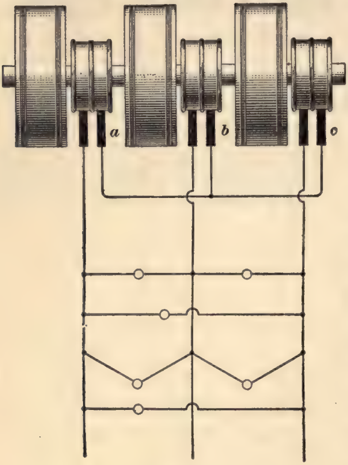


FIG. 17.

22. Multiphase or Polyphase Systems.—The term **multiphase**, or **polyphase**, is applied to any system that uses two or more than two alternating currents that differ

in phase. Two-phase and three-phase systems are the ones most commonly used, though six-phase systems are used in a few special cases. These polyphase systems owe their extended use to the fact that a single alternating current, or a **single-phase current,** as it is usually called, is not well adapted to the operation of alternating-current motors, and where the current is used for power-transmission work, it is necessary to use two or more currents.

MAXIMUM, AVERAGE, AND EFFECTIVE VALUES OF AN ALTERNATING CURRENT.

23. During each cycle an alternating current passes through a large range of values from zero to its maximum. These instantaneous values are, as a rule, used very little in calculations. But it is necessary that it should be clearly understood what is meant when a current of so many amperes is said to be flowing in a circuit or that an alternator is supplying a pressure of so many volts. When it is stated that an alternating current of, say, 10 amperes is flowing in a circuit, some average value must be implied, because, as a matter of fact, the current is continually alternating through a wide range of values. It has become, therefore, the universal custom to express the values of alternating currents in terms of the value of the continuous current that would produce the same heating effect in the circuit; for example, if the alternating current were 10 amperes, it would mean that this alternating current would produce the same heating effect as a 10-ampere continuous current.

24. Suppose that the curve, Fig. 18, represents the variation of an alternating E. M. F.; there are three values of this E. M. F. that are of particular importance:

1. The **maximum value,** or the highest value that the E. M. F. reaches. This value is given by the ordinate

(vertical line) E. This maximum value is not used to any great extent, but it shows the maximum to which the E. M. F. rises, and, hence, indicates the maximum strain to which the insulation of the alternator or any device connected to the circuit will be subjected.

2. The **average value,** which is the average of all ordinates of the curve for one-half a cycle. For example, in Fig. 18 the average ordinate of the curve *a f b* will be that ordinate *a d* that, multiplied by the base *a b*, will give a rectangle *a b e d* of the same area as the surface *a f b*. The average value taken for a whole cycle will be zero, because

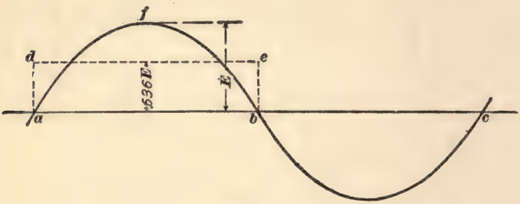


FIG. 18.

the average ordinate for the negative wave will be the equal and opposite of the positive ordinate. This average might be obtained by drawing a number of equally spaced vertical lines, adding them, and then dividing by the number of the lines.

This average value always bears a definite relation to the maximum value. *If E is the maximum value, the average value is* $.636\,E$. The average value is used in some calculations, but, like the maximum value, its use is not very extended. The relation between the average and maximum value is, however, used considerably and should be kept in mind.

3. The **effective value** of an alternating current may be defined as that value that will produce the same heating

effect in a circuit as a continuous current of the same amount. *This effective value is the one universally used to express alternating currents and E. M. F.'s;* it always bears a definite relation to the maximum value. When ammeters or voltmeters are connected in alternating circuits, they always read effective amperes or volts. This effective value is not the same as the average value (.636 max.), as might at first be supposed, but it is slightly greater, being equal to .707 times the maximum value. If a continuous current C be sent through a wire of resistance R, the wire becomes heated, and the power expended in heating the wire is $P = C^2 R$ watts, or it is proportional to the square of the current. If an alternating current be sent through the same wire, *the heating effect is at each instant proportional to the square of the current at that instant.* The average heating effect will, therefore, be proportional to the average of the squares of all the different instantaneous values of the current, and the effective value of the current will be the square root of the average of the squares of the instantaneous values. The effective value is, for this reason, sometimes called the *square-root-of-mean-square* value. It is also frequently called the *virtual value.* Suppose, for example, a circuit in which an alternating current of 10 amperes maximum is flowing. This means that the current is continually alternating between the limits +10 amperes and −10 amperes and passing through all the intermediate values during each cycle. Now, as far as the heating or power effect of this current is concerned, it is just the same as if a steady current of .707 × 10, or 7.07 amperes were flowing, and if an ammeter were placed in the circuit it would indicate 7.07 amperes.

RELATIONS BETWEEN VALUES.

25. The relation between the maximum, average, and effective values will be seen by referring to Fig. 19, the average ordinate .636 E being slightly shorter than the

effective $.707\,E$. For convenience, the following relations are here given together; they should be kept well in mind,

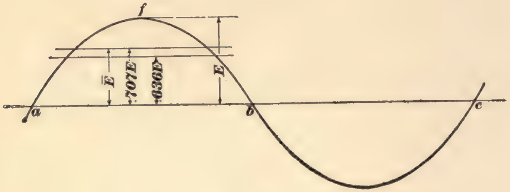


FIG. 19.

as they are used continually in problems connected with alternating-current work:

Average value = .636 maximum value.
Effective value = .707 maximum value.
Effective value = 1.11 average value.

NOTE.—The student must remember that these values only hold for currents and E. M. F.'s that vary according to the smooth waves shown in Figs. 18 and 19. These are known as *sine waves*, or sine curves. Many alternators give E. M. F. and current waves that are very close to a true sine wave, and the ordinary rules and formulas used in alternating-current work are based on the assumption that the current follows such a wave. If the student wishes further information regarding sine curves, he will find them explained in works on Trigonometry. For the present purpose such explanation is not needed and is beyond the scope of this Course.

SELF-INDUCTION.

26. It has already been mentioned in connection with the subject of phase difference that very often where an E. M. F. is causing an alternating current to flow in a circuit, the current may not rise and fall in unison with the E. M. F., but may lag behind it. This effect is due to what is known as *self-induction*, and it is a direct consequence of the continual variation that the current undergoes.

It has already been shown that whenever the number of magnetic lines of force threading through a circuit is caused to change in any way, or whenever a conductor is made to cut lines of force, an E. M. F. is set up in the circuit or conductor, and the average E. M. F. so generated depends on the average number of lines of force cut per second; or, in other words, on the *rate* at which the lines are made to change. As an example, take a circular coil of wire. Lines of force may be made vary through this coil in several ways,

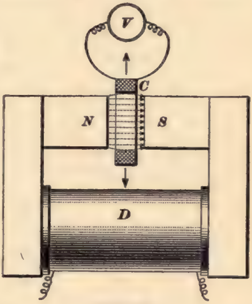


FIG. 20.

one way, for instance, being to bring the coil near the pole of a magnet and then move it so as to cause the number of lines passing through the coil to vary. Consider the arrangement shown in Fig. 20. Here the circular coil C, shown in section, is placed between the poles N, S of the electromagnet, so that the lines of force indicated by the arrows thread through its center. If the coil be moved up and down in the direction of the large arrows, an E. M. F. will be generated and it will be indicated by the voltmeter V. The E. M. F. so generated will be alternating, and the arrangement will constitute an elementary form of alternator. The same effect would be produced if the coil were held still and the magnet moved. Both these methods are in common use in alternators, in one type the coils being mounted on the armature and revolved in front of the magnet, while in the other the coils are held stationary and the field is revolved.

27. Lines of force may also be made thread a coil by sending a current through the coil itself. Take a circular coil as shown in Fig. 21. If a current is sent through such a coil, lines of force will be set up, as shown by the dotted lines. So long as the current remains steady, these lines

will not change, and the current will flow through the coil just as if it were an ordinary resistance, i. e., the current will follow Ohm's law; and if the voltage applied to the terminals is E volts and the resistance R ohms, the current will be determined by the relation $C = \frac{E}{R}$. If, however, the current is made to vary in any way, the number of lines of force threading the coil also varies, and, hence, an E. M. F. is set up in the coil. This E. M. F. of self-induction tends to oppose any change in the current. Whenever, then, there is sent through a circuit an alternating current that can set up lines of force that will thread through the circuit, a counter E. M. F. of self-induction is set up and the current

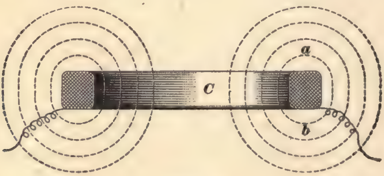


FIG. 21.

no longer flows according to Ohm's law, since the effect of the self-induction is to apparently increase the resistance of the circuit. Of course, there are no self-induction effects present in direct-current circuits, because the current is steady and no induced E. M. F.'s can be set up. Circuits containing resistance can be made that have practically no self-induction, and these are known as *non-inductive circuits.* Such circuits will behave the same with regard to alternating currents as to direct currents, i. e., the current flowing in them will be according to Ohm's law. Water resistances and incandescent lamps are practically non-inductive.

28. Since the induced E. M. F. always depends on the *rate at which lines of force are cut or changed*, it follows that if the coil is so situated that it can readily set up lines of

force through itself, the induced E. M. F. will be large. Also, if there are a large number of turns in the coil, the E. M. F. will be large, because each of the turns will cut the lines of force threading the coil. The higher the frequency of the alternations, the more rapid will be the change in the lines, and, hence, the higher will be the E. M. F. It may then be stated that with a given current flowing through a coil, the induced E. M. F. will be proportional to the total number of lines N threading the coil, the number of turns T, and the frequency n.

29. The total number of lines N that will thread a coil when a given current is sent through it depends on the number of turns T in the coil and the material by which the coil is surrounded. In the case shown in Fig. 21, where the coil is surrounded by air, the self-induction will be comparatively low, because air is a poor conductor of magnetic lines, and with a given current in the coil, a large number will not be set up through it. If, however, the coil is surrounded by iron, as shown in Fig. 22, the self-induction will be enormously increased, because lines of force can be set up very readily. The number of lines that will be set up depends, then, not only on the current, but also on some other quantity, which takes account of the location of the coil and the facility with which lines of force may be set up around it. This quantity is known as the **coefficient of self-induction** or, as it is often called, the **inductance** of the coil, circuit, or whatever piece of apparatus may be under consideration.

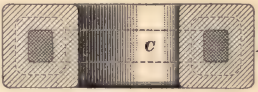


FIG. 22.

30. The coefficient of self-induction for any coil is obtained from the following relation:

The product of the total number of lines N threading a coil when the current is 1 ampere and the number of turns in the coil divided by 100,000,000, or 10^8, gives the coefficient of

self-induction. The coefficient of self-induction is usually denoted by the letter L. From the above, the relation given in formula **1** is obtained:

$$\frac{N \times T}{10^8} = L, \qquad \textbf{(1.)}$$

where N is the number of lines corresponding to a current of 1 ampere, T the number of turns, and L the coefficient of self-induction. The practical unit of self-induction is called the **henry.** If a coil had a coefficient of self-induction of 1 henry, it would mean that if the coil had one turn, 1 ampere would set up 100,000,000, or 10^8, lines through it, as seen from the formula.

The inductance L for a given piece of apparatus is a constant quantity, so long as nothing but air or non-magnetic material surrounds the conductors. In order for L to be constant, the magnetic permeability of the surrounding medium must be constant. If iron is present, L will be nearly constant if the magnetism is not forced too high. In most practical cases, the inductance L may be considered constant just as the resistance R of a piece of apparatus is considered constant.

COMPONENTS OF APPLIED ELECTROMOTIVE FORCE.

31. It has been shown that the effect of self-induction is to choke back the current. It also makes the circuit act as though it possessed inertia, as the current does not respond at once to the changes in the applied E. M. F., and thus lags behind. The resistance of the coil also tends to prevent the flowing of the current, but it does not tend to displace the current and E. M. F. in their phase relations. In considering the flow of current through circuits containing resistance and self-induction, it is convenient to think of the resistance and self-induction as setting up counter E. M. F.'s that are opposed to the E. M. F. supplied by the alternator. The E. M. F. supplied from the alternator or other source must

then, in the case of alternating-current circuits, overcome not only the resistance, but also the self-induction. In the case of continuous-current circuits, the resistance only must be taken into account. In every case, then, where an impressed E. M. F. (the E. M. F. applied to, or impressed, on the circuit) encounters both resistance and self-induction in a circuit, it may be looked on as being split into two parts, or components, one of which is necessary to overcome the resistance and the other the self-induction.

32. Resistance Component.—The part of the applied E. M. F. that is required to overcome the resistance is obtained by multiplying the current by the resistance because, from Ohm's law, $E = C R$. It is evident that when the current is zero, the E. M. F. necessary to overcome the resistance is also zero, because there is no current to force through the resistance. Also, when the current is at its maximum value, the E. M. F. required to overcome the resistance is at its maximum value. *The E. M. F. required to overcome resistance is, therefore, in phase with the current.*

33. Self-Induction Component.—*The component of the applied, or impressed, E. M. F. that is necessary to set up the current against the induced E. M. F., or, in other words, to overcome the self-induction, is at right angles to the current and is 90°, or one-quarter of a cycle, ahead of the current in phase.*

This may be seen by referring to Fig. 23, where the heavy-line wave represents the current flowing in a coil, or circuit. The magnetism set up through the circuit will increase and decrease as the current increases and decreases, and, hence, may be represented by the light-line wave in phase with the current. Now the *induced E. M. F.* is greatest when the magnetism is changing at the most rapid rate, because then the cutting of the lines of force is greatest.

If the student will examine the curve that represents the varying magnetism, he will notice that when the curve is at

its highest point, the magnetism is changing but little; for example, there is little or no change between the lines d, d', as these two lines are of the same length. On the other hand, when the magnetism curve is passing through zero, a small change in time, as, for example, from e to c, is accompanied by a considerable change in magnetism, because the magnetism decreases from the amount at e to zero. In short, the rate of cutting the lines of force, or the *rate of change of the magnetism*, is greatest when the magnetism is passing through zero; hence, the *induced E. M. F.* must be a maximum when the current and magnetism are passing through zero. The induced E. M. F. is, therefore, at right angles to the current. Also, when the current is increasing in a positive direction, the induced E. M. F. must be in the negative

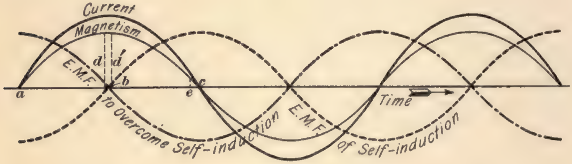


FIG. 23.

direction, because the induced E. M. F. opposes the increase in the current. The dotted curve, Fig. 23, that represents the induced E. M. F. must, therefore, be at right angles to the current and 90° *behind* it. We are not so directly concerned with the induced E. M. F. itself as with the E. M. F. that must be applied to overcome the counter E. M. F. due to self-induction; but it is evident that this E. M. F. required to *overcome* self-induction must be the equal and opposite of the E. M. F. *of* self-induction. The dot-and-dash curve, which is the equal and opposite of the dotted curve, therefore represents the E. M. F. necessary to overcome the induced E. M. F., and it is 90° *ahead* of the current in phase. The student must not forget that the E. M. F. required to *overcome* the self-induction is the equal and opposite of the E. M. F. *of* self-induction.

CIRCUITS CONTAINING RESISTANCE AND SELF-INDUCTION.

34. If we send an alternating current through a load of incandescent lamps or through a water rheostat, we have a circuit in which there is little or no self-induction, or it is a non-inductive load. Under such circumstances the current and E. M. F. will be in phase with each other and the alternating current will behave in the same way as would a direct current. We can apply Ohm's law to find out what E. M. F. will be required to force a given current through the resistance, or we can use the same law to find out what current will flow when a known E. M. F. is impressed, or applied.

35. Suppose, however, that we apply an alternating E. M. F. of, say, 100 volts to a device having a resistance of 2 ohms and an inductance of 1 henry, as shown in Fig. 24. This device may be, for example, a choke coil made by winding a number of turns of insulated wire on an iron core.

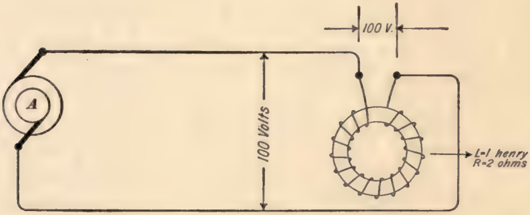


FIG. 24.

In this case, the device through which the alternator A sends current has both resistance and self-induction, and we can no longer apply Ohm's law to find what current will be set up by the applied pressure of 100 volts. If the current followed Ohm's law, it would be equal to $\frac{E}{R}$, or $\frac{100}{2}$ = 50 amperes. As before stated, we may, in a case of this

kind, look upon the E. M. F. as divided into two components, one in phase with the current and the other at right angles to the current. The part in phase with the current is equal to $C \times R$. The component at right angles to the current represents the E. M. F. necessary to overcome self-induction, and this E. M. F. depends on the inductance L and the frequency n of the current, because the more rapidly the current changes, the greater is the induced E. M. F. The induced E. M. F. is given by the following relation:

$$\text{Induced E. M. F.} = 6.283 \times n \times L \times C,^{*} \qquad \textbf{(2.)}$$

where $n =$ the frequency of the current;
$L =$ inductance of the circuit;
$C =$ current flowing in the circuit.

The impressed E. M. F. E is the resultant sum of these two components and is obtained by combining the two by means of the triangle of forces, just as was done with forces

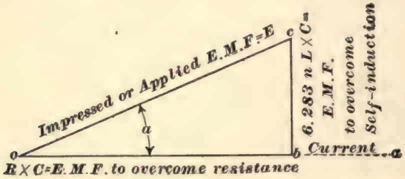


FIG. 25.

as explained in *Principles of Mechanics*. For example, in Fig. 25 let $o\,a$ represent the current, i. e., the line $o\,a$ represents the current to scale, 1 inch being equivalent to a

* The proof of this formula may be found in any of the more advanced works on Alternating Currents. The proof cannot readily be given here, as it is beyond the scope of this Course, and moreover is not necessary for an understanding of the subjects that follow. The quantity 6.283 appearing in formula **2** is equal to 2×3.1416, 3.1416 being the ratio of the circumference of a circle to its diameter. This quantity is often denoted by the Greek letter π (pi), and in many works on Alternating Currents formula **2** is written: induced E. M. F. $= 2\,\pi\,n\,L\,C$.

certain number of amperes; then $o\,b$ in phase with the current will represent the E. M. F. necessary to overcome resistance $= R \times C$. Then the line $b\,c$ at right angles to $o\,b$ will represent the E. M. F. necessary to overcome self-induction, and $o\,c$ will be the resultant of the two E. M. F.'s and must be equal to the applied E. M. F. E. The triangle $o\,b\,c$ is a right-angled triangle; hence, the square on $o\,c$ must be equal to the sum of the squares on $o\,b$ and $b\,c$.

Or, $$o\,c^2 = o\,b^2 + b\,c^2;$$

but $$o\,b = R\,C \text{ and } b\,c = 6.283\,n\,L\,C;$$

hence, $$o\,c^2 = (R\,C)^2 + (6.283\,n\,L\,C)^2,$$

and
$$o\,c = \sqrt{(R\,C)^2 + (6.283\,n\,L\,C)^2} = \sqrt{C^2\,[R^2 + (6.283\,n\,L)^2]}$$
$$= C\sqrt{R^2 + (6.283\,n\,L)^2}.$$

We may, then, represent the different quantities on the E. M. F. triangle as shown in Fig. 26.

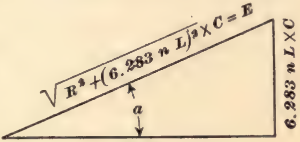


FIG. 26.

36. The student should study Fig. 26 carefully, because it shows the relation and amount of the three E. M. F.'s met in the great majority of alternating-current problems.

These three E. M. F.'s are as follows:

E. M. F. necessary to overcome resistance

$$= R\,C; \qquad \textbf{(3.)}$$

E. M. F. necessary to overcome self-induction

$$= 6.283\,n\,L\,C; \qquad \textbf{(4.)}$$

Impressed E. M. F., or E. M. F. necessary to overcome the resistance and self-induction combined =

$$E = \sqrt{R^2 + (6.283\,n\,L)^2}\,C. \qquad \textbf{(5.)}$$

Of course, the only E. M. F. that is actually present is the impressed E. M. F., but it makes matters clearer if we imagine that the applied E. M. F. is used to overcome the two other imaginary E. M. F.'s. From formula **5** we have

$$C = \frac{E}{\sqrt{R^2 + (6.283\ n\ L)^2}}. \qquad \textbf{(6.)}$$

This may also be put in the form

$$E = C\left(\sqrt{R^2 + (6.283\ n\ L)^2}\right), \qquad \textbf{(7.)}$$

and

$$\frac{E}{C} = \sqrt{R^2 + (6.283\ n\ L)^2}. \qquad \textbf{(8.)}$$

Or, *in an alternating-current circuit, where resistance and self-induction are present, the current is equal to the impressed E. M. F. divided by the square root of the square of the resistance plus the square of 6.283 times the frequency, times the inductance in henrys.*

In other words, formula **6** is the shape that Ohm's law takes for ordinary alternating-current circuits. If the inductance L becomes zero, i. e., if we have a non-inductive circuit, the quantity $(6.283\ n\ L)^2$ becomes zero and we have

$$C = \frac{E}{\sqrt{R^2}} = \frac{E}{R},$$

or when the circuit is non-inductive, the current follows Ohm's law. Or if the frequency reduces to zero, i. e., if the current becomes continuous, n becomes zero and the current follows Ohm's law. The presence of self-induction has, therefore, no influence on the current so long as a direct current is used, because in this case there is no variation in the current to set up a changing magnetic field and the consequent counter E. M. F.

37. In formula **3**, the quantity R, which multiplied by the current C gives the E. M. F. required to overcome

resistance, is, of course, the ohmic **resistance** of the circuit, or the resistance that the wire offers on account of its inherent properties as a conductor; this resistance depends on the length, cross-section, and quality of the wire composing the circuit. The resistance is measured in ohms.

38. Reactance.—In formula **4**, the quantity 6.283 $n L$, which multiplied by the current gives the component of the applied E. M. F. required to overcome the self-induction, is known as the **reactance** of the circuit. It depends on the frequency of the current and the inductance of the circuit, which latter, in turn, depends on the amount of magnetism that the circuit is capable of setting up around itself. Reactance also is expressed in ohms.

39. Impedance.—In formula **5**, the quantity $\sqrt{R^2 + (6.283\, n L)^2}$, which multiplied by the current gives the impressed, or applied, E. M. F., is known as the **impedance** of the circuit. The impedance, as seen from this formula, depends on the values of the resistance and reactance and is equal to the square root of the sum of their squares. As seen from formula **6**, Ohm's law for alternating-current circuits containing resistance and self-induction then becomes

$$\text{Current} = \frac{\text{applied E. M. F.}}{\sqrt{\text{resistance}^2 + \text{reactance}^2}} = \frac{\text{applied E M.F.}}{\text{impedance}}. \quad \textbf{(9.)}$$

40. Angle of Lag.—The angle a, Figs. 27, 28, and 29, is the angle that the current lags behind the applied E. M. F. because the current is in phase with the E. M. F. required to overcome resistance. It is evident from Fig. 28 that if the reactance is large compared with the resistance, the angle by which the current lags behind the impressed E. M. F. will be large, and the effect of the

FIG. 27.

reactance on the current will be large. If, on the other hand, the reactance is very small compared with the resistance, the angle of lag will be small, as shown in Fig. 29, and the value of the current is determined largely by the resistance. If the reactance becomes zero, the angle of lag a becomes zero and the impressed E. M. F. comes into phase with the current.

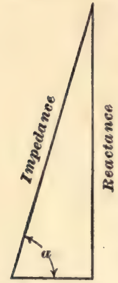


FIG. 28.

41. Coming back to the problem shown in Fig. 24, we can easily calculate the current that the 100-volt pressure will set up by applying formula **6.** We will suppose that the alternator generates an E. M. F. that passes through 30 cycles per second. We have then $n = 30$, $L = 1$, $E = 100$, $R = 2$;

hence, $$C = \frac{100}{\sqrt{2^2 + (6.283 \times 30 \times 1)^2}}$$

$$= \frac{100}{\sqrt{4 + (188.49)^2}} = .53 \text{ ampere. Ans.}$$

If no inductance were present, or if a 100-volt direct E. M. F. were applied to the coil, the current would be $\frac{100}{2}$

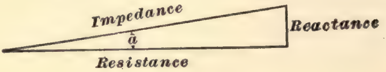


FIG. 29.

$= 50$ amperes, so that the great effect the self-induction has on the flow of the current is easily seen.

EXAMPLES FOR PRACTICE.

1. A 60-cycle alternator is connected to a circuit that has an inductance of .05 henry and a resistance of 10 ohms; what E. M. F. must be supplied by the alternator to force a current of 10 amperes through the circuit? Ans. 213 volts, approx.

2. A 1,000-volt 125-cycle alternator sends a current through a circuit having a resistance of 10 ohms and an inductance of .01 henry; what is the value of the current? Ans. 78.6 amperes

EFFECTS OF CAPACITY.

42. There is another property of electric circuits that must be considered in connection with the flow of alternating currents and that, like self-induction, does not enter into the consideration of the flow of continuous currents. This is the property which most circuits possess to a greater or less degree, of holding a certain charge or quantity of electricity, and is known as *electrostatic capacity;* in some cases it has a marked influence on the behavior of an alternating current flowing in the circuit. The capacity of most circuits met in practice is quite small in comparison with their resistance and inductance, consequently its effect is not usually so noticeable; however, in some cases, especially in underground cable work, these effects become important, and it is necessary to study briefly the behavior of an alternating current when capacity is present in the circuit.

If capacity is needed for any particular purpose, it is usually made up by taking a large number of sheets of tin-foil and separating them by alternate sheets of waxed paper, mica, or other insulating material. The whole mass is pressed tightly together, one set of sheets constituting one terminal and the alternate set the other, as shown in Fig. 30, where *p* represents the tin-foil sheets, *i* the insulating material, and *T* the terminal posts. Such an arrangement is called a **condenser.** It should be noticed, in passing, that there is no electrical connection between the two sets of sheets, or plates.

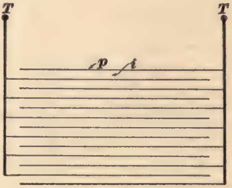


FIG. 30.

43. Long transmission lines have an appreciable capacity, the two wires constituting the plates of the condenser, and the capacity of underground cables is often quite large. In the latter case, the copper conductor constitutes one plate of the condenser and the outer sheath of the cable the other.

CONDENSER CHARGES.

44. If a battery be connected to the terminals of a condenser, as shown in Fig. 31, a current will flow into it and the plates will become charged. This flow of current will be a maximum the instant the E. M. F. is applied, but will rapidly fall off, so that in a small fraction of a second the current will practically have ceased flowing and the condenser will be charged. This will be the state of affairs so long as the condenser remains connected to the battery; i. e., except for the instant when the battery is first connected, no current will flow, and the circuit will act simply as if it were broken. The condenser acts as if it had acquired a counter E. M. F. that tends to keep out the current, and this counter E. M. F. becomes greater until, when the condenser is charged, it is equal and opposite to that of the battery. If the battery be disconnected and the terminals of the condenser connected together, the charge will flow out and will result in a current of short duration. This current will be a maximum when the terminals are first connected, but it soon falls to zero.

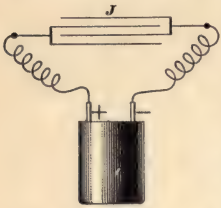


FIG. 31.

45. If a condenser be connected to a source of alternating E. M. F. the condenser will be alternately charged and discharged, and an ammeter inserted in the circuit will give a reading the same as if the current were actually flowing through the condenser. For example, if an alternator is connected to a long transmission line that has considerable capacity, or to a long stretch of underground cable, it will be found that an ammeter in the circuit will indicate a current even though the insulation between the lines may be perfect. This current is known as a **charging current,** because it represents the current arising from the charge that the cable, or line, alternately takes up and discharges as the applied E. M. F. rises and falls.

The effect of capacity is exactly the opposite of self-induction. Capacity tends to make the current lead the E. M. F., while self-induction tends to make it lag; so that if both are present in a circuit, one tends to neutralize the other, and in some cases, condensers have been used for this purpose. The effects of capacity, as stated before, only become appreciable on long lines or underground systems, and are not so frequently met as the effects of self-induction.

The unit of capacity is the **farad.** A condenser has a capacity of 1 farad when a charge of 1 ampere flowing for 1 second (i. e., a charge of 1 coulomb) raises the pressure across its terminals 1 volt. In other words, an applied pressure of 1 volt is able to force a charge of 1 coulomb into a condenser that has a capacity of 1 farad. The farad is too large a unit of capacity for convenient use, so the **micro-farad,** or one one-millionth of a farad, is used in practical work.

POWER EXPENDED IN ALTERNATING-CURRENT CIRCUITS.

46. If a continuous current C flows through a wire of resistance R, the wire becomes heated, and the rate at which work is done in heating the wire is proportional to the square of the current C and to the resistance R; i. e., watts

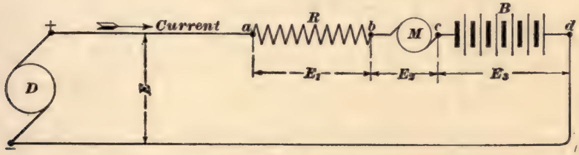


FIG. 32.

expended $= C^2 R$. Since $C = \frac{E}{R}$, we have watts $= C E$. Hence it may be stated that, in a continuous-current circuit, if we wish to calculate the watts expended, we multiply the current C by the E. M. F. E necessary to force the current

through the circuit. This is also true in a circuit where the energy expended reappears in other forms than heat. For example, we might have a direct-current dynamo D, Fig. 32, sending current through a circuit $a\,d$ that consists of a resistance R, a motor M, and a storage battery B. The total power expended in the circuit from a to d will be the product of the current C and the E. M. F. E across the circuit. Part of this energy $= C\,E_1$ will reappear as heat in the resistance R, another part, equal to $C\,E_2$, will reappear as work done by the motor M, and the energy expended in the battery, $C\,E_3$, will be stored up by virtue of the chemical reactions that are caused to take place by the current.

47. *If an alternating current be sent through a circuit, the power expended at each instant is given by the product of the instantaneous values of the current and E. M. F.* It is seen at once, then, that the phase relation between the current and the E. M. F. will have an important bearing on the power supplied, because the value of the E. M. F. corresponding to any particular value of the current will

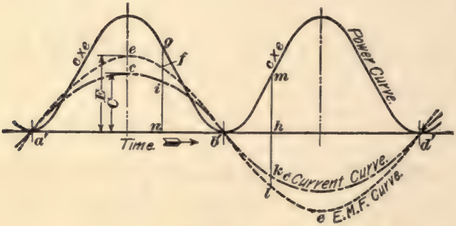


FIG. 33.

depend altogether on their phase relation. In alternating-current circuits, therefore, the power expended cannot be obtained by simply taking the product of the volts and amperes, as is done with direct currents. The effect of the difference of phase between the current and the E. M. F. on the power expended can be illustrated by means of the curves shown in Figs. 33 to 37, inclusive. Suppose that an

E. M. F. of maximum value E is in phase with a current of maximum value C, as shown in Fig. 33, the current being represented by the dot-and-dash curve c and the E. M. F. by the dotted curve e. The power at any instant, such as that represented by the point n, is proportional to the product of the ordinates $n\ i$ and $n\ f$ of the c and e curves. If an ordinate $n\ g$ is, therefore, erected at n proportional to this product, g will be a point on the power curve. In this way the power curve shown by the full line is constructed, and it shows the way in which the power supplied to the circuit varies with the E. M. F. and the current. It should be noticed that in this case (current and E. M. F. in phase) the power curve lies wholly above the horizontal; that is, the work is all positive, or, in other words, power is being supplied to the circuit at every instant. This would be the condition if the current were flowing through a non-inductive resistance.

48. Suppose, however, that the current lags behind the E. M. F. by an angle less than 90°, as shown in Fig. 34. The power curve is here constructed as before, but it is no longer wholly above the horizontal. The ordinate $f\ g$ of the current curve is positive, while at the same instant

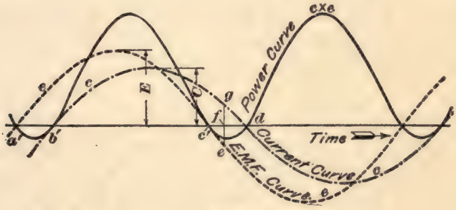


FIG. 34.

that of the E. M. F. curve $f\ e$ is negative, consequently their product is negative, and the corresponding ordinate of the power curve is below the horizontal. This means that during the intervals of time $a'\ b'$ and $c'\ d$, *negative work* is being performed; or, in other words, the circuit, instead of

having work done on it, is returning energy to the system to which it is connected. In Fig. 35 the angle of lag has become 90°, or the current is at right angles to the E. M. F. In this case the power curve lies as much above the axis as below it, and the circuit returns as much energy as is expended in it. The total work done in such a case is, therefore, zero, and although a current is flowing, this current does not represent any energy expended. This would be nearly the case if an alternator were supplying current

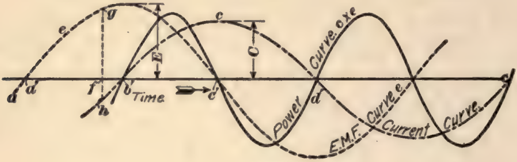


FIG. 35.

to a circuit having a small resistance and a very large inductance, as in this instance the current would lag nearly 90° behind the E. M. F. The primary current of a transformer working with its secondary on open circuit is a practical example of a current that represents very little energy. Such a current at right angles to the E. M. F. is, for the above reasons, known as a **wattless current,** because the product of such a current by the E. M. F. does not represent any watts expended.

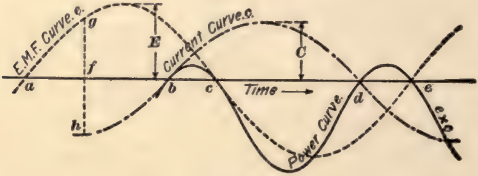


FIG. 36.

49. If the angle of lag becomes greater than 90°, the greater part of the work becomes negative, as shown in

Fig. 36. If the angle of lag becomes 180°, as in Fig. 37, i. e., if the current and E. M. F. are in opposition, the work done is all negative, and, instead of the alternator doing work on the circuit to which it is connected, the circuit is returning energy to the alternator and running it as a motor.

50. The curves in Figs. 33 to 37 show the value of the watts expended at each instant for different values of the angle of lag. What we usually wish to know is the average rate at which energy is expended and not the rate at each instant, the above curves being given simply to show the effect of the lag on the power expended. In Fig. 33, where the current and the E. M. F. are in phase, the power is always positive and the average power is obtained by taking the product of the effective values of the current and E. M. F. in just the same way as with a direct current. In

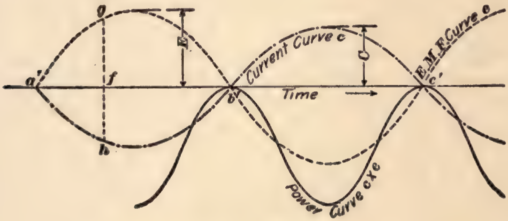


FIG. 37.

Fig. 35, where the angle of lag is 90°, as much of the power curve is below the line as above it, and the result is that the average power is zero. In Fig. 34, the average power would not be zero, but it would be less than in Fig. 33. It is quite evident, then, that the true power expended in an alternating-current circuit cannot be obtained by simply multiplying the current and E. M. F. together. Another factor must be introduced to take into account the difference in phase between the current

and E. M. F. This quantity is known as the **power factor,** and if it is represented by f, we have

$$W = C \times E \times f, \qquad \textbf{(10.)}$$

where $W =$ number of watts actually expended in the circuit;
$E =$ E. M. F. in volts;
$C =$ current in amperes;
$f =$ power factor.

The product $C \times E$ is sometimes called the **volt-amperes,** or **apparent watts,** supplied to the circuit, while W is the actual number of watts or **real** watts supplied. It follows, then, from formula **10** that

$$\text{power factor} = \frac{\text{real watts}}{\text{apparent watts}}. \qquad \textbf{(11.)}$$

51. For continuous-current circuits and for alternating-current non-inductive circuits, the current and the E. M. F. are in phase and the power factor is 1. The watts are, therefore, obtained by simply multiplying together the ammeter and voltmeter readings. Where alternating-current motors are operated, the power factor may be less than 1, say, from .80 to .90. The power factor may vary from 1 to zero. It would have a value of zero in case the E. M. F. were at right angles to the current, as shown in Fig. 35, because there the actual power expended is zero; although a considerable E. M. F. and current may be present. Of course, a zero power factor is seldom, if ever, met in practice, but power factors anywhere from .5 up to 1 are common. The power factor of motors, transformers, and other alternating-current devices varies to some extent with the load. The effects of a low-power factor on alternating-current circuits will be considered later. For the present the student should note carefully the effect that the difference in phase between the current and the E. M. F. has on the power, and also that the product of volts and amperes in an alternating-current circuit will in most cases give a number of apparent

watts that will be considerably greater than the number of actual watts.

EXAMPLE.—A current of 10 amperes at a pressure of 500 volts is supplied to an alternating-current circuit that has a power factor .85; what is the actual number of horsepower furnished?

SOLUTION.—From formula **10**, we have

$$W = 10 \times 500 \times .85 = 4{,}250,$$

and since 1 horsepower = 746 watts,

$$\text{H. P.} = \frac{4{,}250}{746} = 5.7, \text{ nearly. Ans.}$$

ALTERNATING CURRENTS.

(PART 2.)

SINGLE-PHASE ALTERNATORS.

GENERAL CHARACTERISTICS.

1. Dynamo-electric machines used for the generation of alternating E. M. F.'s are known as **alternators.** It was shown in the theory of the dynamo that the E. M. F. generated in the armature of a direct-current dynamo is essentially alternating, and that the commutator is supplied to preserve the relation of the external circuit so that the current in it may be direct. It follows, therefore, that if the proper terminals of a continuous-current armature were connected to two collector rings in place of a commutator, the current furnished would be alternating. In the majority of cases, however, alternator armatures are not wound in the same way as are those for continuous current, and the E. M. F. is more generally produced by moving a set of

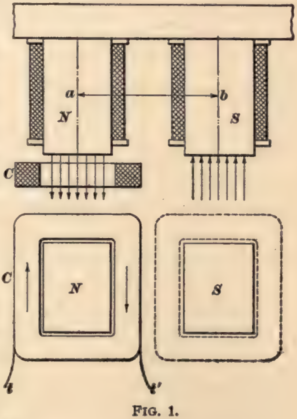


FIG. 1.

coils past pole faces rather than by revolving loops or coils, as is done in direct-current drum armatures. In other words, the movement of the coils is best looked on as one of translation rather than rotation. As an example of this, consider a horseshoe electromagnet, shown in Fig. 1. When such a magnet is excited by means of the coils on its two limbs, lines of force flow from the north pole N into the south pole S, as indicated by the arrows. The two pole faces are shown in the lower diagram, and the rectangular coil of wire C is supposed to be moved across the pole face N to the position shown by the dotted outline in front of S. When the coil is in the position shown under the north pole, a small movement of the coil to the right will not cause a very large change in the number of lines threading it, consequently only a small E. M. F. will be induced. While the conductors are moving under the pole pieces, the E. M. F. will be practically uniform if the field is uniform, and when the coil has reached the position shown by the dotted line, the E. M. F. will again be zero. The E. M. F. has, therefore, passed through one alternation, or half cycle, while the coil has been moved through the distance $a\,b$. This E. M. F. curve may be of the shape shown in Fig. 2,

FIG. 2.

the portion at y being fairly uniform while the conductors are moving under the poles; or it may have a different shape, depending on the shape of the coil and pole pieces as well as on the way in which the magnetic lines are distributed. No matter what may be the shape of the curve $a\,y\,b$, the *E. M. F. passes through one alternation when the coil is moved a distance equal to that from the center of one pole to the center of the next.* If the coil C be moved back from S to N, the same set of values of the E. M. F. is generated in the opposite direction; hence, by moving the coil from N to S and back,

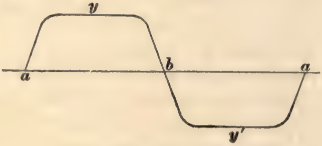


FIG. 3.

the E. M. F. passes through one complete cycle, as shown in Fig. 3. The arrangement shown in Fig. 1 would, therefore, constitute an elementary alternator, and the E. M. F. would be set up by movements of the coil back and forth across the pole faces, there being no rotation at all. Instead of moving the coil back and forth, the same effect could be produced by moving the coil forwards, continuously, in front of a row of poles, as shown in Fig. 4. As the coil *C* moves past the poles, it cuts the lines of force first in one direction and then in the other,

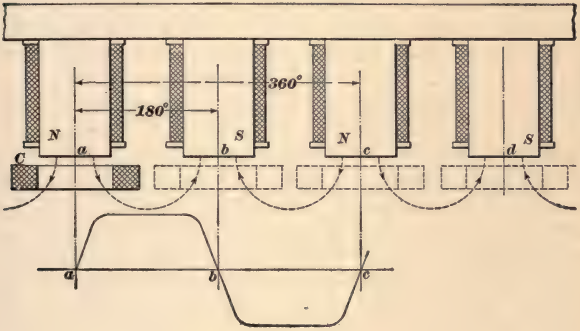


FIG. 4.

thus producing the alternating E. M. F. represented by the curve below. It should be noted that while the coil moves through the distance between one north pole and the next pole *of the same polarity*, the E. M. F. passes through one complete cycle. The distance from *a* to *c*, therefore, corresponds to 360° on the E. M. F. curve, and *a b* to 180°. For every *pair of poles* passed, the E. M. F. passes through a *complete cycle of values;* hence it follows that the *number of cycles per second or the frequency of an alternator is equal to the number of pairs of poles that the armature winding passes per second.* If the number of poles on the machine

is p, the number of pairs of poles is $\frac{p}{2}$, and if the coil is moved past the poles s times per second, the frequency n will be

$$n = \frac{p}{2} s. \qquad \textbf{(1.)}$$

2. Instead of the single coil C, Fig. 4, being used by itself, three other coils, shown dotted, might be connected in series or parallel with C and the four moved together in front of the poles. If the coils were connected in series, it is evident that the total E. M. F. produced would be increased, because all the E. M. F.'s generated in the turns of the different coils would be added up. If they were connected in parallel, the E. M. F. would be the same as that produced by the single coil, but the current-carrying capacity would be increased, because there would then be four circuits to carry the current in place of one. It should be noted particularly that no matter how many coils there are or how they are connected together, the frequency remains the same so long as the speed s and the number of poles is constant. In other words, the *frequency* of an alternator does not depend on the way in which the armature is wound. Connecting the coils in series is equivalent to making the winding of one coil of a large number of turns; connecting them in parallel amounts to the same thing as winding in one coil with a heavy conductor. As long, therefore, as the coils are all moved simultaneously, as is always the case, the frequency is not affected in any way by the scheme adopted for winding and connecting up the armature.

3. It is evident that an alternating E. M. F. would be set up in the coil or set of coils, Fig. 4, if the magnet were moved and the coils held stationary. Also, both coils and magnet might be stationary and an E. M. F. still be induced by causing the lines of force threading the coils to vary. These three methods give rise to the following three classes of alternators:

1. Those in which the armature coils are moved relatively to the field magnet.

2. Those in which the field is moved relatively to a fixed armature.

3. Those in which the magnetic flux passing through a fixed set of coils is made to vary by moving masses of iron, called *inductors*, past them.

For convenience in referring to alternators, we will suppose that the armature is the revolving part and that the field is fixed, though it must be remembered that actual machines may be built with any of the three arrangements mentioned above.

CONSTRUCTION OF ALTERNATORS.

4. The most common type of alternator is that in which the coils are mounted on a drum and revolved in front of a magnet consisting of a number of radial poles. Alternator armatures may be of the ring, drum, or disk type, but the drum style is used almost exclusively in America. If we suppose the poles, Fig. 4, to be bent into a circle and the coils mounted on a drum revolving within the poles, we will have one of the most common types of alternators. This arrangement is shown in Fig. 5, except that in this case the machine is provided with eight radial poles and eight coils on the armature, giving a style of winding in common use for machines used on lighting circuits. In this case there are as many coils on the armature as there are poles on the machine; but a winding might easily be used in which there would be only half as many coils as poles. There is a large variety of windings suitable for alternators, and the designer must select the one best suited to the work that the machine will have to do. In Fig. 5 the coils C are shown bedded in the slots p on the circumference of the iron core P, which is built of thin iron stampings. These coils are heavily taped and insulated and are secured in place by hardwood wedges w.

This makes a style of armature not easily injured, and the use of the dovetailed slots and wooden wedges does away with the necessity of band wires. As the armature revolves, the coils sweep past the pole faces, and the E. M. F. is generated in the manner shown in Fig. 4, i. e., the movement of the coils relative to the pole pieces becomes one of translation rather than of rotation.

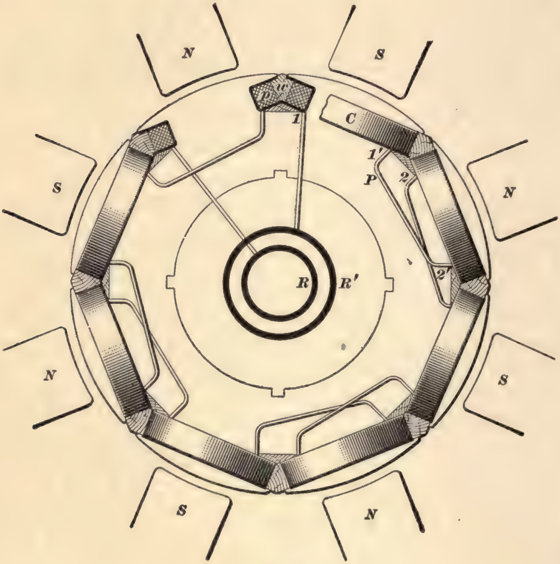


FIG. 5.

5. Alternators are generally required to furnish a high voltage, and, in consequence, the armature coils are usually connected in series. Care must be taken in connecting such windings to see that the coils are so connected that none of the E. M. F.'s oppose one another. By laying out a diagram of the winding, the manner in which the coils must

be connected will be easily seen. This has been done in Fig. 6, which shows diagrammatically the winding of the armature in Fig. 5. The coils are represented by the heavy sector-shaped figures and the connections between them by the lighter lines. The circles in the center represent the collector rings of the machine and the radial lines that part of the coil that lies in the slot, that is, the part in which the

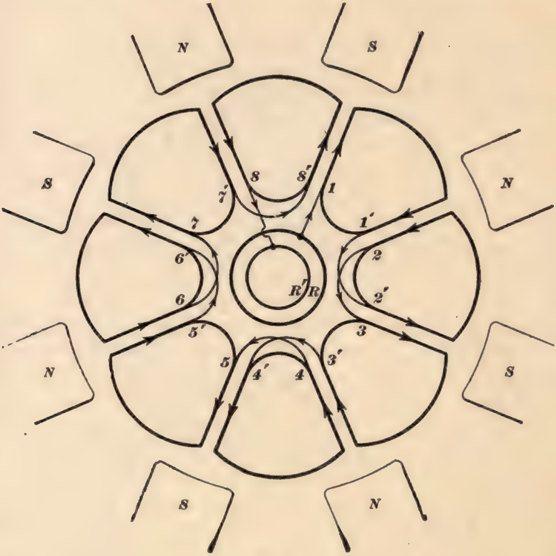


FIG. 6.

E. M. F. is generated. The circular arcs joining the ends of the radial lines represent the ends of the coils that project beyond the laminated armature core.

The drawing is made to show the coils at the instant the conductors in the slots are opposite the centers of the pole pieces. At this instant the E. M. F. will be assumed to be at its maximum value, and we will suppose that the direction

of rotation is such that the conductors under the north poles have their E. M. F.'s directed from the back of the armature towards the front. These E. M. F.'s will be denoted by an arrowhead pointing towards the center of the circle, since the inner end of the radial lines represents the front or collector-ring end of the armature. The E. M. F.'s in the conductors under the south poles must be in the opposite direction, or pointing away from the center. After having marked the direction of these E. M. F.'s, it only remains to connect the coils so that the current will flow in accordance with the arrows. Starting from the collector ring R and passing through the coils in the direction of the arrows, it is seen that the connections of every other coil must be reversed; i. e., if *1*, *1'*, *2*, *2'*, etc. represent the terminals of the coils, *1'* and *2'* must be connected together, also *2* and *3*, and so on. The end *8* is connected to the other collector ring and the winding thus completed. The connections of such a winding are quite simple; but if not connected with regard to the direction of the E. M. F.'s, as shown above, the armature will fail to work properly. For example, if *1'* were connected to *2*, *2'* to *3*, and so on around the armature, the even-numbered coils would exactly counterbalance the odd-numbered ones and no voltage would be obtained between the collector rings. Of course, in this case all the coils are supposed to be wound in the same direction, as is nearly always done in practice. The connections shown in the diagram, Fig. 6, are shown between the coils in Fig. 5. It should be noted, in passing, that this constitutes an open-circuit winding; that is, the winding is not closed on itself, like that of a continuous-current drum or ring armature. A large number of alternator windings are of the open-circuit type, which is well adapted for the production of high voltages, because it admits of a large number of turns being connected in series.

6. Most alternating-current dynamos of the revolving-armature and stationary-field type are built on much the same lines as direct-current multipolar machines. Usually,

however, they have a larger number of poles. Fig. 7 shows a common type of alternator having a revolving armature *a* and a stationary field *f*, with inwardly projecting poles on which are placed the spools *s*. This is an eight-pole machine with an armature winding similar to that shown in the diagram, Fig. 6. The two collector rings *r*, *r'* are seen mounted on the end of the shaft outside the bearing, and

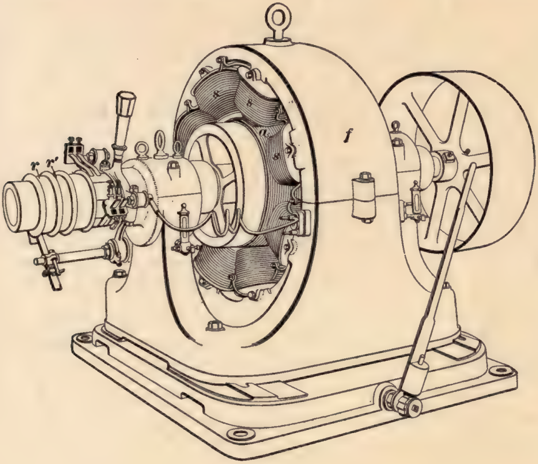


FIG. 7.

are connected to the armature winding by heavily insulated leads that pass through a hole in the shaft. Some machines have the collector rings on the armature side of the bearing, thus avoiding the necessity of bringing the wires through the shaft but making the distance between the centers of the bearings greater.

7. The number of poles on these machines is made large, in order to obtain the necessary frequency without running the machine at too high a speed. It is evident

from what has been previously pointed out that for every revolution of the armature, the E. M. F. passes through as many complete cycles as there are pairs of poles, and the frequency will be $n = \frac{p}{2} s$, where p = number of poles and s = revolutions of the armature per second.

We have then,

$$n = \frac{p}{2} \times s;$$

$$s = \frac{2n}{p}. \qquad (2.)$$

Therefore, with a given frequency n, the number of poles must be made large if the speed s is to be kept down. For example, if an alternator has eight poles and runs at a speed of 900 revolutions per minute, its frequency will be $\frac{8}{2} \times \frac{900}{60}$ = 60 cycles per second. If we attempt to obtain a frequency of 60, which is a very common one, by using a two-pole machine, its speed must be $s = \frac{2 \times 60}{2}$, or 60 revolutions per second, or 3,600 revolutions per minute, which speed is altogether too high for a machine of any considerable size.

8. The distance $e f$, Fig. 8, from the center of one pole piece to the center of the next is called the **pitch** of the alternator. The relation between the pitch and the width of the pole face A varies in different makes of machines, but in a large number of American alternators the distance B between the poles is made equal to the width of the pole face A, or $\frac{1}{2}$ the pitch, and the pole pieces cover 50 per cent. of the armature. The shape of the E. M. F. curve is determined largely by the relative shape of the coils and pole pieces and by the way in which the conductors are disposed on the surface of the armature.

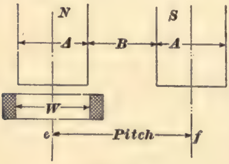


FIG. 8.

9. The width of the opening W in the coil should not, in general, be much less than the breadth of the pole piece A. It has been found that it may be slightly less without doing any harm; but if made too narrow, trouble is likely to arise because the E. M. F.'s induced in different conductors of the same coil are opposed to each other, thus cutting down the total E M. F. generated.

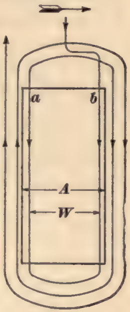


FIG. 9.

This will be seen by referring to Fig. 9, where a coil of three turns is shown with its width of opening W less than the polar width A. When the coil moves across the pole face in the direction of the arrow, the E. M. F.'s induced in the two conductors a and b will both be in the same direction, because they both cut lines of force in the same way. The consequence is that these two E. M. F.'s oppose each other, as will be readily seen by following the arrowheads. When an alternator is loaded, the armature reaction causes the magnetism to crowd more or less towards one side of the poles, thus practically reducing the width of the magnetic flux, and on account of this it has been found possible to make the width W a little less than A without bad results. Usually, however, the width of the opening is nearly equal to that of the pole face.

FIELD EXCITATION OF ALTERNATORS.

10. In most alternating-current systems, the voltage at the points where the current is distributed is kept constant, or nearly so. This means that the voltage at the terminals of the alternator must, as a rule, rise slightly as the load comes on, the amount of rise depending on the loss in the line. At any rate, the voltage at the terminals must not drop off, and, as it has been shown that with a constant field excitation the voltage will fall off with the load, it becomes necessary to increase the strength of the field magnets as the current output of the machine increases. For accomplishing

this there are two methods in use, which are analogous to those used for the regulation of shunt-wound and compound-wound continuous-current machines.

11. The simplest method is that indicated by the diagram, Fig. 10. *W* represents the armature winding, the terminals *T*, *T'* of which are connected to the collector rings *R*, *R'*, which connect to the line by means of the brushes *g*, *h*. The field is excited by a set of coils on the pole pieces represented by *C*, and current is supplied to these

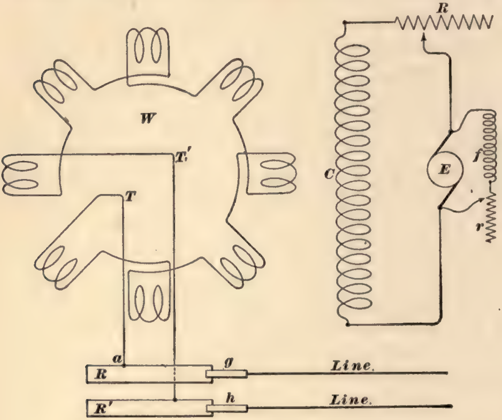


FIG. 10.

from a small continuous-current dynamo or **exciter** *E*. This is a small shunt-wound machine having an adjustable field rheostat *r* in its shunt field *f*. An adjustable rheostat *R* is placed also in the alternator field circuit. When the voltage drops, the fields may be strengthened by adjusting the resistances *R* and *r*.

12. The second method, shown in Fig. 11, varies the excitation of the field in proportion to the current that the machine is supplying, and thus automatically keeps up the voltage. Each field coil in this case consists of two windings

similar to those used on compound-wound continuous-current dynamos. One set of windings is separately excited by means of the exciter E and is provided with a rheostat R, as in the previous case. The field of the exciter is also provided with a rheostat r. The greater part of the current furnished by the alternator flows through the series winding

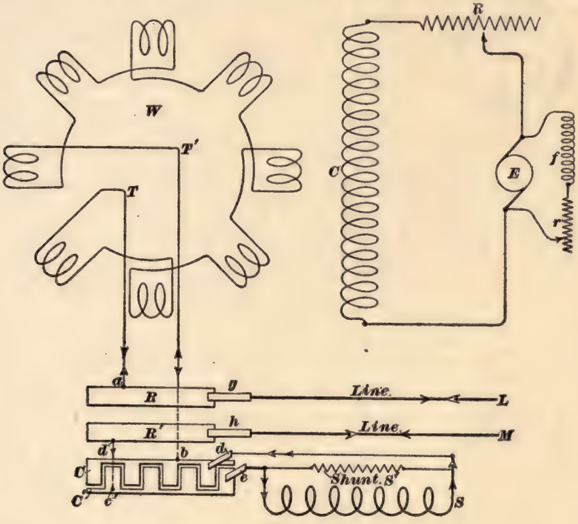


FIG. 11.

represented by the heavy coil S; and since this causes the magnetism to increase, the machine maintains its voltage. The separately excited coils set up the magnetism necessary for the generation of the voltage at no load, and the series coils furnish the additional magnetism necessary to supply the voltage to overcome the armature impedance and compensate for the drop in the line.

13. The current flowing in these series coils must not be alternating, because if it were it would tend to strengthen the poles one instant and reverse them the next, and on

this account the current must be *rectified* before it is sent around the field.

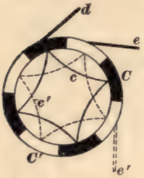


FIG. 12.

This is accomplished by means of the commutator, or **rectifier**, $C\ C'$, which is mounted on the shaft alongside the collector rings. It consists of two castings C, C' (shown developed in the figure) that are fitted together and form a commutator of as many sections as there are poles in the machine. The alternate sections are connected by the conductors c, c', as shown in Fig. 12, the light sections belonging to one casting C' and the dark to the other C. Two brushes d and e, which press on the commutator, are so arranged that one is always in contact with C while the other touches C'. The connections are as shown in the diagram. One terminal T of the armature winding connects directly to the ring R and thence to the line. The other terminal T' connects to one side of the rectifier C, and the other side C' is connected to the remaining ring R'. By following the direction of the current, it will be seen that while the rectifier causes the current to flow in the same direction in the series coils S, it still remains alternating in the line circuit. Take the instant when the coils occupy such a position that the current is flowing from the terminal T and mark the direction of flow in the different parts of the circuit by the closed arrowheads. The current will flow on the line L, back on M to C', through S, flowing from left to right, back to C, and thence back to the armature. When the armature has turned through a distance equal to that between two poles, the current will be flowing in the opposite direction, as indicated by the open arrowheads; that is, it will be flowing out from T' to C, from C it will go to the brush e instead of d, because it must be remembered that the rectifier has turned through the same angle as the armature, and hence d has slid from C on to C'. From e the current flows through S in *the same direction as before* back to C', out on the line M, and back on L to T. The action of the rectifier is,

briefly, to keep changing the connections of *d* and *e* as the current changes, thus keeping the current in *S* in the same direction while it remains alternating in the line. Usually the brushes *d*, *e* are placed on the commutator as shown by *d* and *e'*, Fig. 12, in order to have them farther apart, their action, however, being the same. A shunt resistance *S'* is usually placed across the coils *S*, in order to adjust the compounding of the machine to suit the circuit on which it is to work, since by varying *S'*, the percentage of the total current passing around the field can be changed.

14. Another method is used in which the main current, instead of passing through the rectifier and series coils, flows through the primary of a small transformer carried in the armature. The secondary of this transformer is connected to the rectifier and supplies the series field with a current that varies directly with the load. This method is used largely on Westinghouse machines.

REVOLVING-FIELD AND INDUCTOR ALTERNATORS.

15. It has been mentioned previously that it makes no difference in the case of an alternator whether the field or armature is the revolving part. It is hardly practicable to make a direct-current dynamo with a revolving field and a stationary armature, because it is necessary that the brushes should always press on the commutator at certain neutral

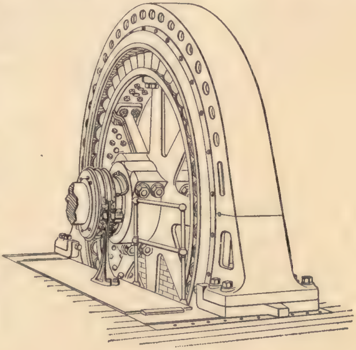


FIG. 13.

points that bear a fixed relation to the field, and the brushes would, therefore, have to revolve with it. This, of course, would be impracticable, because it is often necessary to get at the brushes while the machine is running. In an alternator the brushes pressing on the collector rings do not have to bear any fixed relation to the field, consequently there is no objection to the use of a fixed armature, the current from which can be carried off by leads connected to the winding. Two collector rings are necessary for carrying the exciting current into the revolving field, so that the use of the stationary armature does not do away with moving contacts. The revolving-field type has an advantage in that the armature, being stationary, is easy to insulate for high voltages. This construction also admits of the ready use of armatures of large diameter, thus rendering such machines particularly adapted to slow speeds. Fig. 13 shows a large revolving-field alternator.

16. In the inductor type of alternator, the collector rings for supplying current to the field may be done away with and a machine obtained that has no moving contacts whatever. In this class of machine, a mass of iron or **inductor** with projecting poles is revolved past the stationary armature coils. The magnetism is set up by a fixed coil encircling the inductor, and as the iron part revolves the magnetism sweeps over the face of the coils, thus causing an E. M. F. to be set up.

TWO-PHASE ALTERNATORS.

17. Since a two-phase machine delivers two currents differing in phase by 90°, it follows that the two windings on its armature must be so arranged that when one set is delivering its maximum E. M. F., the E. M. F. of the other set is passing through zero. It has been shown that while the coils move from a point opposite the center of one pole piece to a point opposite the next pole piece *of the same*

polarity, the E. M. F. passes through one complete cycle; hence, if the E. M. F.'s generated by the two sets of coils are to be displaced 90°, or $\frac{1}{4}$ cycle, with reference to each other, it follows that one set of coils must be placed one-half the pitch behind the other. This brings one set of conductors under the poles while the other set is midway between them.

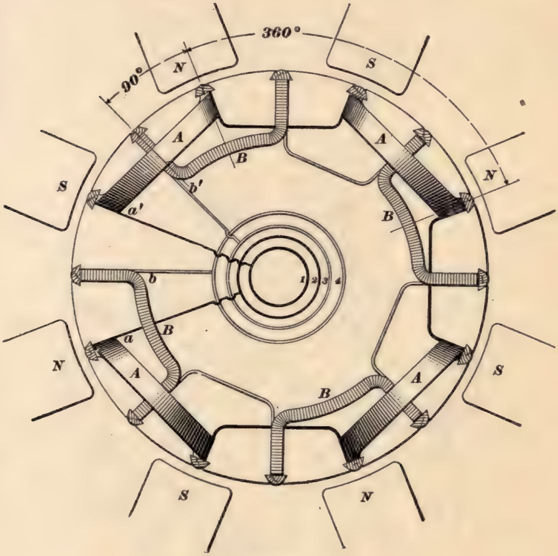


FIG. 14.

Fig. 14 represents a two-phase winding having one group of conductors or one-half a coil per pole per phase. One phase is made up of the four coils A, which are connected in series, and the terminals a, a' brought out to the collector rings *1*, *2*. The four coils B, which make up the second phase, are also connected in series, and the terminals b, b' attached to the light collector rings *3*, *4*. The angular

distance by which the center of set B is displaced from set A is equivalent to 90°, or $\frac{1}{4}$ cycle, as indicated in the figure, the angular distance from N to N being equivalent to 360°, or one complete cycle.

THREE-PHASE ALTERNATORS.

18. The requirement of a three-phase armature winding is that it shall furnish three E. M. F.'s differing in phase by 120°, or one-third of a complete cycle. This can be done

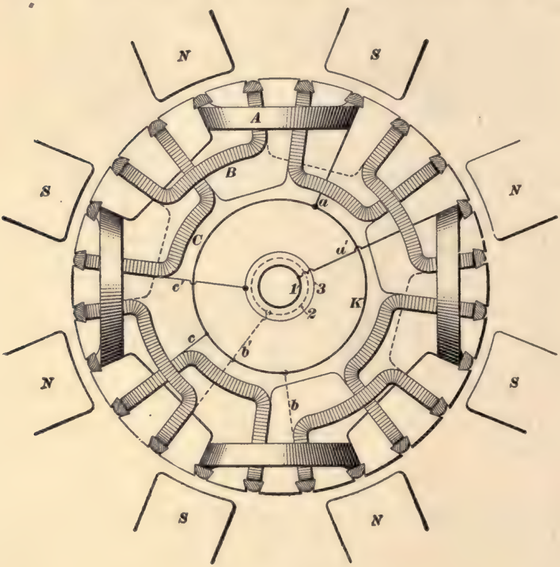


FIG. 15.

by furnishing the armature with three sets of windings displaced 120° from each other. This means that phase No. 2 must be one-third the angular distance from one north pole

to the next north pole behind phase No. 1, and also that phase No. 3 shall be displaced a similar angular distance behind No. 2.

On many actual machines three sets of windings are used that are displaced on the armature a distance equivalent to 60° instead of 120°. One of these windings is, however, reversed so as to make the three E. M. F.'s delivered at the terminals of the machine differ in phase by 120°.

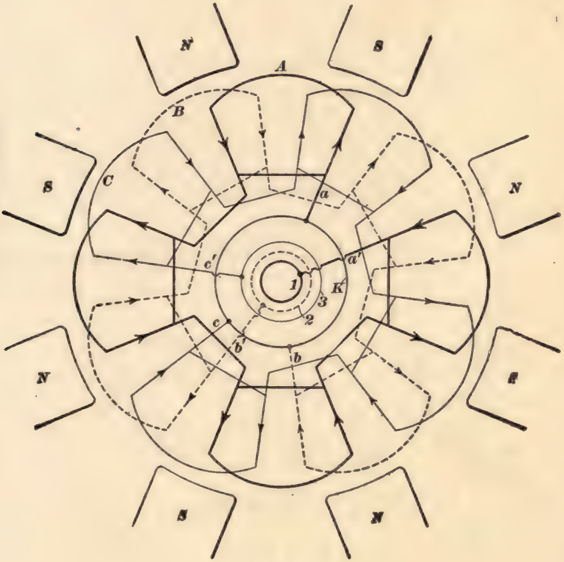


FIG. 16.

19. Fig. 15 shows a three-phase winding having one-half coil or one group of conductors per pole per phase. This is the three-phase winding corresponding to the two-phase arrangement shown in Fig. 14. The winding consists of three distinct sets of coils *A*, *B*, and *C*. The angular

distance from the center of coil B to A is equivalent to 120°, or is one-third the distance from N to N; also the coil C is displaced the same distance behind B. Each of these three sets is connected in series, leaving the three pairs of terminals a, a'; b, b'; c, c'. The coils are shown diagrammatically in Fig. 16, phase *1* being represented by the heavy lines, phase *2* by the dotted, and phase *3* by the light full lines.

STAR AND DELTA CONNECTIONS.

20. It has been shown that the three windings of a three-phase alternator can be interconnected so that only three collecting rings will be required. There are two methods by which this may be done. The first is that shown in Fig. 17, and is known as the **Y** or "star" scheme of connection. The coils Fig. 16 are connected according to this

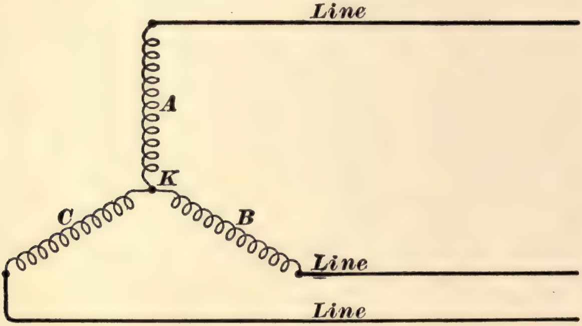


FIG. 17.

plan. One end of each of the windings runs to a common connection K, Fig. 17, or, as shown in Fig. 16, the terminals a, b, c all connect to the same common connecting ring. The remaining three ends of the three groups of coils are connected to separate collecting rings.

The second method of connecting three-phase armatures is known as the Δ (delta) or "mesh" method, and is shown in Fig. 18.

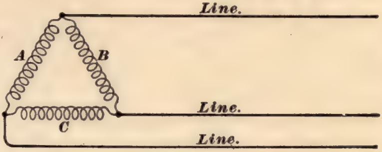


FIG. 18.

Here the three windings *A*, *B*, and *C* are connected together so as to form a closed circuit, and the three collecting rings are connected, one to each of the three points where the windings join one another. Both the Y and Δ methods of connecting are in common use.

MONOCYCLIC ALTERNATOR.

21. The monocyclic alternator, brought out by Steinmetz, is intended for use in stations where the greater part of the load consists of electric lights, but where it is also desired to have a machine capable of operating motors as well. In cases where the motor load is large, it is usual to use a regular two-phase or three-phase system.

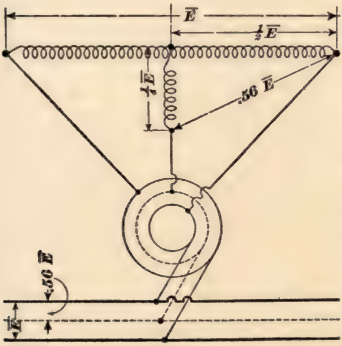


FIG. 19.

The monocyclic alternator is really a single-phase machine having a modified armature winding. The armature is provided with a set of coils constituting the main winding, the terminals of which are connected to the two outside collector rings, Fig. 19. In addition to this winding, a second

set of coils is provided, that are placed on the armature 90° behind the main coils, in just the same way as shown for the two-phase machine, Fig. 14. This second set is unlike those in a regular two-phase machine in that the number of turns in the "teaser coils," as they are called, is only one-fourth that of the main set, and one end of the teaser set is attached to the middle of the main winding, instead of being brought out to a collector ring. The other end of the teaser winding is brought to the middle collector ring, as shown in Fig. 19. This second winding furnishes an E. M. F. displaced 90° from the main E. M. F. and of one-quarter its value, thus furnishing an out-of-phase pressure suitable for starting motors. If it is desired to run lights only, the two outside wires alone are used, it being necessary to run the third wire only to places where motors are used. By referring to the figure, it will be seen that the E. M. F. between either of the outside and the middle rings is equal to $\sqrt{(\frac{1}{2}E)^2 + (\frac{1}{4}E)^2} = .56\,E$, nearly. For example, if the main winding generates 1,000 volts, the pressure between the middle and outside rings will be 560 volts, nearly.

22. Field Excitation of Multiphase and Monocyclic Alternators.—Multiphase alternators differ very little from single-phase machines as regards their field excitation. Most of the large-size multiphase machines as now built have revolving fields which are separately excited. No rectifiers are used on these machines, and the general tendency seems to be towards discontinuing the use of rectifiers and compound windings, especially on machines of large output. When a compound winding is used on Westinghouse two-phase machines, it is supplied from the secondary of a transformer carried in the armature. This secondary connects to the series winding through the rectifier. The primary of the transformer is provided with two coils, one of which is connected in each phase, so that the current supplied by the secondary is proportional to the loads on the two phases. In the General Electric monocyclic machines, the rectifier and series coils are in series with the main circuit, as already

described for single-phase machines. In the case of three-phase machines, the rectifier is frequently connected in one phase only, as the load is usually nearly balanced. In other cases, the rectifier is arranged so that the current of each line flows successively through the series winding.

TRANSFORMERS.

23. One of the principal reasons for the fact that continuous current is giving place so largely to alternating current is the ease with which the latter may be transmitted over long lines at high voltages and then be transformed at the receiving end to currents of lower pressure suitable for operating lights, motors, or other devices. If power is to be transmitted over long distances by means of the electric current, it is absolutely necessary that high line pressures be used in order to make the cost of the conductors reasonably low.

Devices used for changing an alternating current of one voltage to another of a higher or lower voltage are known as **transformers** or **converters.** The first name is the one now generally applied to these devices. Transformers may be used either to "step-up" the voltage, i. e., increase it, or they may be used to "step-down," or decrease, the line pressure. Whether the transformer be used to step up or down, the change in pressure is always accompanied by a corresponding change in the current, and the *power* delivered to the transformer is always a little greater than that obtained from it. For example, suppose a current of 20 amperes were supplied to a transformer from 1,000-volt mains. If the load on the transformer were non-inductive, the E. M. F. and current would be almost exactly in phase, and the watts supplied to the side connected to the mains (*primary* side of the transformer) would be 20 × 1,000, or 20,000 watts. The power obtained from the *secondary* side, or the side connected to the circuit in which the power is being used, would not be quite as much as this.

Suppose the secondary E. M. F. were 100 volts; if there were no losses whatever in the transformation, we would obtain 20,000 watts from the secondary, and the available secondary current would be $\frac{20000}{100} = 200$ amperes. In other words, the decrease in E. M. F. has been accompanied by a corresponding increase in current. As a matter of fact, there is always some loss in conversion, and the secondary output is never quite equal to the power supplied to the primary. The ratio $\frac{\text{watts output}}{\text{watts input}}$ gives the efficiency of the transformer. A good transformer is one of the most efficient pieces of apparatus known, some of large size delivering as much as 98.5 per cent. of the energy supplied.

24. Transformers used for changing an alternating current at one pressure to an alternating current at another pressure are often called *static transformers*, because they have no moving parts. This is done to distinguish them from *rotary transformers*, which are used to transform alternating currents into direct currents, or *vice versa*. Such machines always have moving parts, hence their name. Nearly all transformers are operated on constant-potential systems. The transformer is supplied with current from mains, the pressure between which is kept constant, and this current is transformed to one of higher or lower pressure, the secondary pressure also being constant or nearly so.

PRINCIPLE OF THE TRANSFORMER.

25. A simple transformer is shown in Fig. 20. C is a laminated iron ring on which are two coils P and S. The coil P has a certain number of turns T_p, and S has, we will suppose, a smaller number of turns T_s. The coil P is the primary and is connected to the alternator mains across which the constant pressure E_p is maintained. We will suppose, for the present, that the resistance of both the primary and secondary coils is negligible.

The above is essentially the construction of the ordinary static transformer. It consists of two coils or sets of coils interlinked by an iron magnetic circuit. Of course the forms of different transformers vary widely, but they all contain the three essential parts mentioned.

Suppose a voltmeter V to be connected to the terminals of the secondary coil S. The resistance of the voltmeter is very high, consequently a very small current will flow

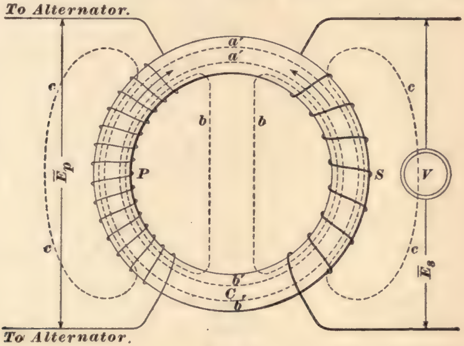


FIG. 20.

through the secondary coils, and we may, for all practical purposes, consider the secondary coil as an open circuit in which no current is flowing. The line E. M. F. E_p will cause a current to flow through the primary coil, and this current will set up an alternating magnetic flux in the iron core. This alternating flux will set up a counter E. M. F. in the coil P, which will be very nearly the equal and opposite of E_p.

The current that will flow, therefore, in the primary coil when the secondary coil is on open circuit is the current that is required to set up a magnetic flux N capable of producing a back E. M. F. equal and opposite to the applied E. M. F. Since the coil P is wound on a closed, iron magnetic circuit, it is evident that a small current in P will be capable of setting up a large amount of magnetism

through itself, provided there is no opposing force. The current that flows in the primary coil when the secondary coil is on open circuit is, therefore, very small, because the primary coil has a high self-induction and chokes back the current by virtue of the counter E. M. F. that is set up. The magnetic flux set up in the iron circuit by the coil P passes through the secondary coil S also, and because of the fact that this flux is always changing, an E. M. F. will be set up in the coil S and will be indicated by the voltmeter V. The amount of this secondary E. M. F. will depend on the number of turns with which S is wound. If S has fewer turns than P, E_s will be less than E_p and the transformer will step down. If S has the same number of turns as P, E_s will equal E_p. If S has a greater number of turns than P, E_s will be greater than E_p and the transformer will step up.

26. The ratio of the primary voltage to the secondary at no load, i. e., $\frac{E_p}{E_s}$, is called the **ratio of transformation.** Also the ratio of transformation is equal to the primary turns divided by the secondary turns. For example, if a transformer be supplied with 1,000 volts primary and has 500 turns on its primary coil while there are 50 turns on the secondary, the ratio of transformation is 10 and the secondary voltage $1,000 \times \frac{50}{500} = 100$ volts. In this case the transformer reduces the voltage from 1,000 to 100, but the operation could be reversed, that is, it could be fed with 100 volts and the pressure raised to 1,000.

27. It was assumed above that all the magnetic flux N that threaded the primary coil also passed through the secondary, and in well-designed transformers this is very nearly the case. However, some lines may leak across, as shown by the dotted lines b, b, c, c, without passing through both coils. This is known as **magnetic leakage.**

If the transformer is poorly designed, this magnetic leakage may become large when the transformer is loaded, and thus cause a falling off in the secondary voltage. The resistance

of the primary and secondary coils also causes the secondary voltage to drop off somewhat as the transformer is loaded, because a part of the E. M. F. is required to force the current through the coils against their resistance.

When a load is attached to the secondary, Fig. 20, a current flows through S, and this current is opposite in phase to the current in the primary; the secondary, therefore, tends to set up an opposing magnetic flux. The curved arrows in Fig. 20 represent the way in which these two fluxes oppose each other. The effect of the current in the secondary is to cut down the choking effect of the primary and thus allow more current to flow through the primary. As, therefore, the load is applied to the secondary, the current in the primary increases in proportion, and the transformer takes a current from the line that is proportional to the load that the secondary carries.

28. Transformer Losses.—The student must remember that no transformer gives out quite as much energy from its secondary as it takes in in its primary. There is always some unavoidable loss. These losses are of two kinds, namely, $C^2 R$, or *copper*, *loss* and *hysteresis* and *eddy current* or *iron losses*. These are similar to the losses that take place in the armature of a dynamo. **Copper loss** is due to the heating of the coils on account of their resistance and thus increases rapidly as the load increases. The **hysteresis** or **iron loss** is caused by the continual reversal of the magnetism in the iron. The loss due to **eddy currents** in the core can be made very small if the core is carefully laminated. The hysteresis loss can only be kept down by using a very good quality of iron in the core and avoiding high magnetic densities in it.

29. Regulation.—If a transformer is supplied with a constant primary pressure, the secondary pressure will also remain nearly the same no matter what the load may be. There will be a slight falling off in voltage from no load to full load, which is due to the resistance of the coils and the

fact that there is always some magnetic leakage between the primary and secondary coils; but if the transformer is well designed, this falling off will be slight. The reaction of the secondary coil is such that as the load increases, the primary current also increases, but the secondary voltage remains nearly the same. The primary voltage is, of course, maintained at a constant value by the alternator supplying the current.

CONSTRUCTION OF TRANSFORMERS.

30. Transformers are made in a variety of forms, but they may, for convenience, be divided into two general classes: (*a*) Core transformers; (*b*) shell transformers.

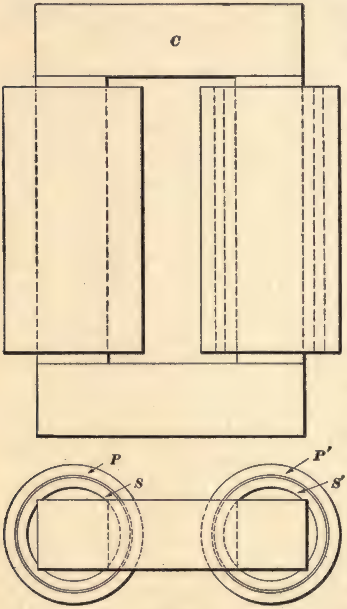


FIG. 21.

In the **core transformer,** the iron part forms a core on which the coils are wound, while in the other arrangement the iron surrounds the coils. Figs. 21 and 22 show the arrangement of the parts of a common type of core transformer. The core C, Fig. 21, is built up of thin iron strips into the rectangular form shown; P, P', S, S' are the primary and secondary coils, each being wound in two parts. It will be noticed that the primary is wound over the secondary, thus making the

leakage path between the coils long and of small cross-section, thereby reducing the magnetic leakage.

Fig. 22 shows a section of the coils and core.

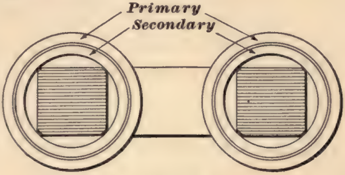


FIG. 22.

One advantage of this type is that the core may be built up of strips of iron, no special stampings being required. There is also an advantage in having the coils wound in two sections, in that it enables the transformer to be connected for a variety of voltages. For example, suppose each primary coil were wound for 1,000 volts and each secondary for 50 volts. By connecting the primary coils in series or parallel, the transformer could be operated on 2,000- or 1,000-volt mains, and by connecting the secondaries in series or parallel, a secondary voltage of either 100 or 50 could be obtained. Modern transformers are usually built in this way because it is often convenient to be able to make these changes.

31. Figs. 23 and 24 show a common type of **shell transformer.** Here the primary and secondary coils P, P_1 and

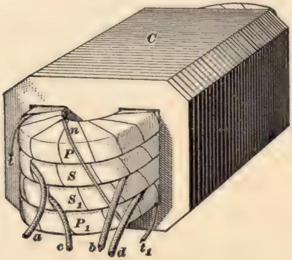


FIG. 23.

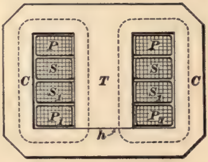


FIG. 24.

S, S_1, respectively, are surrounded by the iron core C, which is built up of iron stampings of the form shown in the

sectional view, Fig. 24. A cut is made in the stamping at *h*, so that the tongue *T* may be bent back to allow the stampings to be slipped over the coils. The magnetic lines are set up around the circuit, as indicated by the dotted lines, and thus pass through both primary and secondary coils. The primary and secondary coils are split into two sections, the primary being divided into two parts and placed on each side of the secondary. The two parts of the primary coils are connected in series by the connection shown at *n*; t and t_1 are the primary terminals. The ends *a* and *b* of coil *S* and *c* and *d* of coil S_1 are brought out separately, in order that the two coils may be connected either in series or in parallel, as may be desired. Leakage tends to take place between the coils, and by interleaving the primary and secondary the leakage is reduced.

32. Transformers for outside work are placed in a weather-proof iron case, such as is shown in Fig. 25. This shows a case suitable for a transformer of the style shown in Fig. 21. The wires *a*, *b* are the primary terminals, and *c*, *d*, *e*, *f* are connected to the secondary mains. The case in which transformers are placed is often filled with an insulating oil that not only tends to keep the insulation better, but also helps to get rid of the heat by conducting it from the transformer to the iron case, and thence to the outside air.

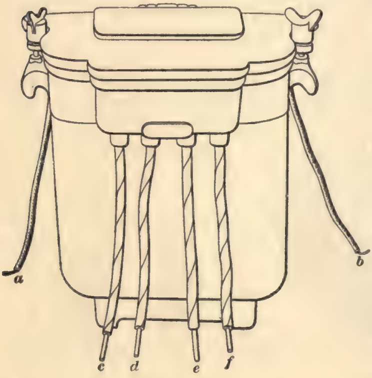


FIG. 25.

The ratio of transformation for transformers used in

ordinary lighting work is usually 10 or 20, that is, 1,000 or 2,000 volts primary and from 50 to 200 volts secondary.

33. Selection of Transformers.—In selecting transformers for a given lighting or power system, only the best should be obtained, even if the first cost is somewhat higher than those of less reliable make. A poor transformer will waste more power in the course of a few years than it is worth. For example, suppose a transformer has a large core loss. This loss goes on all the time that the pressure is applied to the primary whether the secondary is delivering any current or not, and the cost of this power may amount to a surprisingly large amount in the course of a year. All transformers are bound to have some core loss, but, as a general rule, cheap transformers of a given output have a larger loss than those of a more expensive but more reliable make, because in the latter case greater care is taken in the selection of the iron in the core. Moreover, the core loss is liable to increase greatly the longer the transformer is used, if proper care is not taken in designing the transformer and in selecting the iron. This effect is known as **aging** and appears to be due to changes brought about in the character of the iron by the long-continued heating while the transformer is in action. The only remedy is to take down the transformer core and anneal the sheets. Transformer builders have paid considerable attention to this subject and are now able, by carefully selecting the iron or mild steel used for the core and by designing their transformers to work at a low temperature, to do away largely with this effect.

34. Insulation Test for Transformers.—It is extremely important that the insulation of transformers shall be good. If the primary should, in any way, come into contact with the secondary, the high pressure would be applied to the secondary lines and bring about a very dangerous condition of affairs. A number of fatal accidents have occurred that have been traced to defective

transformer insulation, and before any transformers are put into service they should be tested to see that their insulation is all right. New transformers are generally tested at the factory, but before any old or second-hand transformers are put into service, they should be subjected to a test by applying a high-pressure alternating current to the windings. Measurements of the insulation resistance by means of a Wheatstone bridge are useless for a test of this kind. Fig. 26 shows the general scheme of connections for a high-potential test as applied to testing the insulation between the primary and secondary coils of the transformer *T*. The high pressure needed for testing is usually obtained from

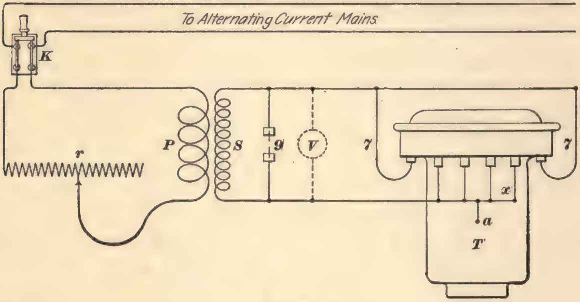


FIG. 26.

a special high-potential, step-up transformer, though if this is not available a number of ordinary transformers may be used with their fine-wire coils connected in series, so as to give the high pressure desired. The main switch *K* is connected to the primary coil *P* through an adjustable resistance *r* that enables the high pressure generated in the secondary *S* to be regulated. The ends 7, 7 of the primary coil of the transformer under test are connected together and to one end of *S*. The ends *x* of the secondary coils are also connected together, grounded on the case at *a*, and connected to the other terminal of *S*. It is important that the various terminals of the coils be connected as indicated, otherwise

some parts of the winding will be subjected to greater strains than others. When the switch K is thrown in, the high E. M. F. generated in S tends to break down the insulation between the primary and secondary coils of T. The applied pressure should be at least three times the primary pressure at which the transformer is designed to work; i. e., a 2,000-volt transformer should stand a pressure of at least 6,000 volts between its primary and secondary coils.

35. In order to determine the applied voltage, a spark gap *9* between needle points or a static high-reading voltmeter V may be used. It has been found by experiment that the voltage required to jump between needle points in air increases almost in direct proportion to the length of the gap, until about 30,000 volts is reached; 30,000 volts (alternating) will jump about $1\frac{1}{2}$ inches in air between bright needle points; 15,000 volts will jump about $\frac{3}{4}$ inch; 10,000 volts, $\frac{1}{2}$ inch; and so on. By setting the points, say, $\frac{1}{2}$ inch apart and then raising the voltage, by cutting out r, until a spark jumps across, it is known that the pressure applied to the transformer is about 10,000 volts. If needle points are used, they should be renewed after every discharge, otherwise they become corroded and give inaccurate results.

36. In applying high-potential tests, care must be taken not to permanently strain and injure the insulation. It is all well enough to apply a test that will indicate to a certainty that the insulation will be capable of standing the strain put on it in service, but if the test is made unnecessarily severe, good apparatus may be permanently injured. High-potential tests should not, therefore, be long continued—a few seconds is sufficient to show whether the insulation is defective or not; a longer application will only serve to injure good insulation. High-potential tests should be made when the apparatus is hot, because then the insulation is weaker than when cold, and any weak spots will be more likely to show themselves; besides, the transformer is warm when used under actual operating conditions.

ALTERNATING-CURRENT MOTORS.

37. Motors designed for use in connection with alternating currents may be divided into two classes: (1) Synchronous motors, and (2) induction motors.

Both kinds are in common use, and by far the larger part of all the motors operated in connection with the alternating current belong to one or other of these classes. There are a few other motors that are used to some extent, but their number is insignificant when compared with those of the above two classes.

SYNCHRONOUS MOTORS.

38. **Synchronous motors** are made to operate either on single-phase or polyphase systems, and are so called because they always run in synchronism with, or at the same frequency as, the alternator driving them. In construction they are almost identical with the corresponding alternator, and always consist of the two essential parts, the field and the armature, either of which may revolve. The field of such motors must be excited from a separate continuous-current machine in the same way as an alternator. The fields of synchronous motors are, however, very seldom compound-wound, and hence no rectifier is required; otherwise, the whole construction of the motor is about the same as that of the alternator.

39. If a single-phase alternator be connected to another similar machine, the latter will not start up and run as a motor, because the current is rapidly reversing in its armature, thus tending to make it turn first in one direction and then in the other. The consequence is that the armature does not get started from rest. If, however, the second motor be first run up to such a speed that the frequency of its alternations is the same as that of the alternator, and then connected into circuit, the impulses of current will tend

to keep it rotating, and the machine will continue running as a motor. The motor must be run up to synchronism by means of some outside source of power, and the fact that single-phase synchronous motors will not start of their own accord is a serious drawback to their use. On the other hand, polyphase synchronous motors will start from rest and run up to synchronism, but such motors take quite a large current from the line, and they will not start at all under any heavy load. They must, therefore, be started first and the load applied afterwards, when they will continue running in synchronism with the alternator and will take current from the line in proportion to the work done. Large synchronous motors are often started by means of a small induction motor that is thrown out of use after the large machine has been brought up to synchronism. Single-phase synchronous motors are now seldom used.

40. Synchronous motors behave differently in some respects from direct-current machines. If the field of a direct-current motor be weakened, the motor will speed up in order to maintain the proper value of the counter E. M. F. If the field strength of a synchronous motor be changed, the speed cannot change, because the motor must keep in step with the alternator. Such a motor adjusts itself to changes of load and field strength by the changing of the phase difference between the current and E. M. F.

Imagine a synchronous motor that runs perfectly free when not under load. If this machine were run up to synchronism and its field adjusted so that the counter E. M. F. of the motor were equal and opposite to that of the dynamo, no current would flow in the circuit when the two were connected. At any instant the E. M. F. that causes current to flow is the difference between the instantaneous E. M. F. of the alternator and the counter E. M. F. of the motor. If the motor be loaded, its armature will lag a small fraction of a revolution behind that of the alternator and the motor E. M. F. will no longer be in opposition to that of the alternator, consequently a current will flow that is sufficiently

large to enable the motor to carry its load. The greater the load applied, the larger will be the current that is thus allowed to flow.

It must be borne in mind that this phase difference is caused by a small relative lagging of one armature behind the other, not by a difference in speed. For example, the change of phase from full load to no load might not be more than 25°, and this would mean an angular displacement on the machine of a little more than one-fourth a pole face. If the machine be loaded too heavily, the slipping of the motor armature will become sufficiently great to throw the motor out of synchronism, and it will come to a standstill.

41. Since polyphase synchronous motors will, when not loaded, run up to synchronism of their own accord, they are largely used for power-transmission purposes in places where a large starting effort is not required and where the motor is not started and stopped frequently. They have an advantage over induction motors in that they do not produce lagging currents, and are therefore better adapted for power-transmission plants. What was said with regard to alternator armature windings also applies to synchronous motors, such motors being built for either two-phase or three-phase systems.

42. The speed at which a synchronous motor will run when connected to an alternator of frequency n is $s = \frac{2n}{p}$, where s is the speed in revolutions per second and p the number of poles on the motor. For example, if a 10-pole motor were run from a 125-cycle alternator, the speed of the motor would be $\frac{2 \times 125}{10} = 25$ revolutions per second, or 1,500 R. P. M. It follows from the above that if the motor had the same number of poles as the alternator, it would run at exactly the same speed, and any variation in the speed of the alternator would be accompanied by a corresponding change in the speed of the motor.

INDUCTION MOTORS.

43. In a great many cases it is necessary to have an alternating-current motor that will not only start up of its own accord, but one that will start with a strong torque. This is a necessity in all cases where the motor must start up under load. It is also necessary that the motor be such that it may be started and stopped frequently, and, in general, that it may be used in the same way as a direct-current motor. These requirements are fulfilled by *induction motors.*

44. Induction motors are usually made for operation on two-phase or three-phase circuits, although they are sometimes operated on single-phase circuits by using special starting devices. They consist of two essential parts, namely, the *primary*, or field, to which the line is connected, and the *secondary*, or armature, in which currents are induced by the primary. Either of these parts may be the revolving member, but we will suppose in the following that the field is stationary and that the armature revolves. In a synchronous motor or direct-current motor, the current is led into the armature from the line, and these currents, reacting upon a fixed field provided by the stationary field magnet, produce the motion. In the induction motor, however, two or more currents differing in phase are led into the field, thus producing a magnetic field that is constantly changing and that *induces* currents in the coils of the armature in the same way that currents are induced in the secondary coils of transformers. These induced currents react on the field and produce the motion of the armature. It is on account of this action that these machines are called induction motors.

FIELD WINDING.

45. The winding on the field of an induction motor is almost exactly the same as that on the armature of a synchronous motor or polyphase alternator. The field structure is built up of disks having teeth on their inner circumference that form slots when the core is assembled. The coils are

placed in these slots, forming a winding like that on the surface of a polyphase armature. The winding, when completed, resembles very much the evenly distributed arrangement of

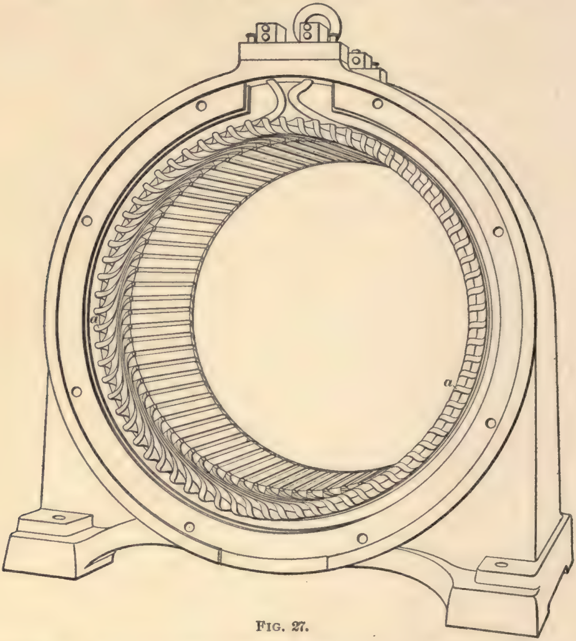


FIG. 27.

coils on a continuous-current armature. Fig. 27 shows a finished field for an induction motor. The coils are seen at *a*, *a* distributed evenly around the inner circumference.

ACTION OF INDUCTION MOTOR.

46. In order to understand the action of an induction motor, it will help matters to compare it briefly with the action of an ordinary direct-current motor. Suppose we

have a four-pole direct-current armature surrounded by its field. If the field is excited and current sent into the armature through the brushes in the ordinary way, the armature will revolve; and the greater the load placed on the machine, the more current will it take to drive the armature. Suppose that instead of driving the armature in this way we remove the brushes and press a copper ring over the commutator so as to connect all the bars together. This will connect all the ends of the armature coils together, making them form a number of closed circuits. Also, suppose that we revolve the field around the armature instead of having it stand still, as is usually the case, and that the armature be held from turning. The lines of force from the field will cut across the armature conductors and set up E. M. F.'s in them. Since the coils are all short-circuited by the rings on the commutator, the result is that heavy currents are set up, and these currents reacting on the field produce a powerful dragging action on the armature. If, therefore, the armature is released, it will be dragged around after the field. If the armature revolved at exactly the same speed as the field, the conductors would move around just as fast as the lines of force; no E. M. F.'s would be set up in the armature conductors and no turning effort or torque would result. It follows, then, that the armature must always revolve a little slower than the field, in order that any drag may be exerted. It should be noticed that in this arrangement no current is led into the armature from outside; it is *induced* in the armature by the revolving field.

The field in this case is supposed to be excited by continuous current and is revolved by mechanical means; but by using two or three alternating currents displaced in phase, we can make the magnetism sweep around the armature without actually revolving the field frame itself. In other words, we can set up magnetic poles that will be continually shifting around the armature without actually revolving the field structure. Fig. 28 will show how this is carried out by using two currents differing in phase. F is the field frame having, in this case, eight polar projections (four for each

phase), on each of which is wound a coil. Coils No. *2*, *4*, *6*, and *8* are connected in series, every other coil being reversed as shown. The terminals b, b' of this series of coils are connected to phase No. *2* of the alternator. The other four coils are joined in the same way and are connected to terminals a, a' of phase No. *1*. The current in each of these phases is constantly changing, and when the current in one phase is

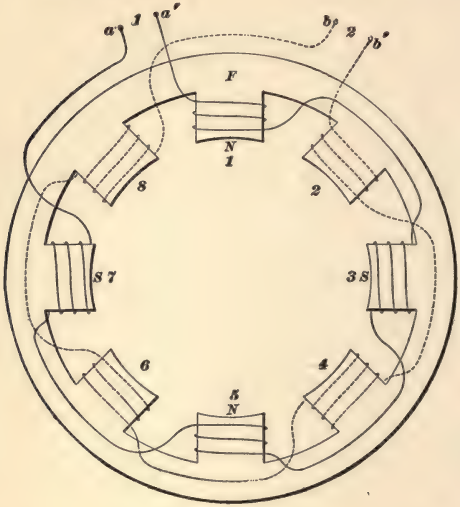


FIG. 28.

at its maximum, the current in the other phase is zero. Suppose that we consider the instant when the current in phase No. *1* is a maximum; the current in phase No. *2* at the same instant will be zero and there will be no magnetism in poles *2*, *4*, *6*, or *8*. Suppose the current is flowing in such a direction in phase No. *1* that a north pole is formed at *1*, then there will be a south pole at *3*, a north pole at *5* and a south pole at *7*. After one-quarter of a cycle has passed, the current in phase No. *1* will be zero and the current in phase

No. *2* will have increased to its maximum value; there will then be no magnetism in poles *1*, *3*, *5*, and 7, and we will have a north pole at *2*, a south pole at *4*, and so on. At the end of the next quarter cycle the current in phase No. *1* will again be at its maximum value, but will be flowing in the opposite direction to what it did before. We will then have a south pole at *1*, a north pole at *3*, and so on. The result of these changes is that the poles keep shifting around, and we have practically the same effect as if we had a four-pole field structure actually revolving. Of course the current in the coils does not change suddenly, but the magnetism in the poles dies away and increases as the current changes.

The style of field generally used is shown in Fig. 27. The principle is the same as that shown in Fig. 28, but the winding is split up into a large number of small coils placed in slots instead of using a few coils on projecting poles.

47. Fig. 29 shows the type of armature commonly used. It is extremely simple in construction and consists of a laminated iron core provided with slots, in each of which is placed a heavy copper conductor *b*. These conductors project at each end of the core and are bolted to the copper rings *r*, *r* that connect all the bars together and thus form a number of closed circuits. An arrangement of this kind is often referred to as a "squirrel-cage" armature, because the conductors and end rings resemble a squirrel cage.

When such an armature is placed in the field shown in Fig. 27 and the current turned on, the magnetic field sweeps around the armature and cuts the bars and sets up currents in the closed circuits formed by the bars and the end rings. There is a powerful drag exerted on the armature, and it is very soon brought up to such a speed that the torque produced by the current in the armature is just sufficient to enable the machine to carry the load. If a heavier load is applied, the speed of the armature drops a little, and thus makes the relative cutting of the lines of force between the armature and field greater, or the *slip* between the

armature and field becomes greater. The difference in speed between the revolving armature and the revolving field of an induction motor is known as the **slip.** The slip is usually expressed as a percentage of the speed that the motor would run at when in synchronism with the dynamo. For example, if the synchronous speed of an induction motor were 900 R. P. M., and if the slip were

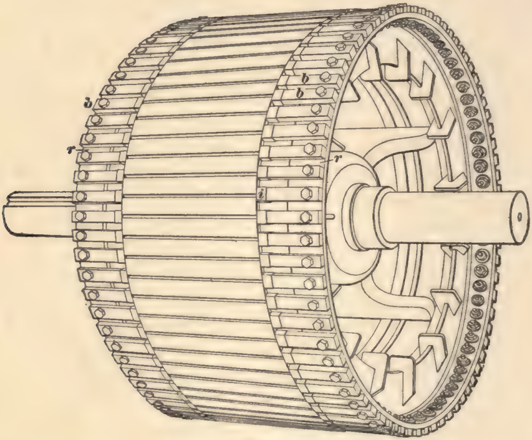


FIG. 29.

2 per cent. at full load, the armature at full load would run 18 R. P. M. slower than the revolving field, and the full-load speed of the motor would be 882 R. P. M. This increases the E. M. F. in the armature, causes more current to flow, and thus increases the torque to the amount necessary to carry the load. The motor, therefore, adjusts itself to changes in load by a slight dropping in speed, just as in the case of an ordinary shunt-wound continuous-current motor.

48. Starting Resistance.—For some kinds of work requiring large starting torque, it is best to have the armature winding so arranged that a resistance may be inserted

in series with it while the motor is starting up and cut out when full speed is attained. If this is not done, there will be a large rush of current at starting, because, when the motor is standing still it is in the condition of a transformer with its secondary short-circuited, and since the armature is stationary with regard to the field, a fairly high E. M. F. might be induced, thus causing a very heavy current to flow through the low-resistance secondary winding.

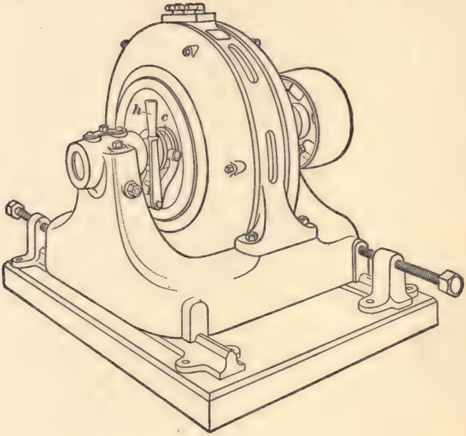


FIG. 30.

This would cause a large current to flow in the primary, and would, therefore, be objectionable. Moreover, this large secondary current so reacts on the field produced by the primary as to greatly weaken it and results in a very small starting torque. If the armature were so designed as to have a fairly high resistance in itself, in order to limit the starting current and procure a good starting torque, the motor would be inefficient and would give bad speed regulation. It is therefore best to have a resistance that may be placed temporarily in the circuit and then cut out.

This may be done by supplying the secondary with a regular winding similar to that of the field and bringing the terminals to collector rings. By means of these rings, connection may be made to a resistance box and resistance cut in or out in much the same way as is done in starting up direct-current motors. In the General Electric Company's motors, the use of collector rings is avoided by mounting the resistance on the armature spider and cutting it out by a switch operated by a sliding collar on the shaft. This enables the motor to be built without any moving contacts whatever. Fig. 30 shows an induction motor of this kind. In this case the sliding collar *c* is operated by the handle *h*. When the speed of an induction motor has to be varied, it is customary to provide the armature with a regular **Y** winding and collector rings, so that an adjustable resistance may be inserted in each phase of the armature winding. Another method of speed regulation is to insert an adjustable resistance or reactance in each phase of the field winding. This avoids the use of collector rings, but the first method is the better and is the one most largely used. Unless a large torque with moderate line current is required at starting, the ordinary squirrel-cage type of armature is used, as it is simpler and cheaper than the type using resistance. By using a starting compensator with a squirrel-cage armature, the line current can be kept down to a reasonable amount.

ROTARY CONVERTERS.

49. It is often necessary to change direct currents to alternating and *vice versa*, and machines for accomplishing this are known as **rotary converters.** The transformation might be effected by having an alternating-current motor coupled to a direct-current generator, simply using the alternating current to drive the motor. An arrangement of two machines is, however, not usually necessary, although such motor-generator sets are used to some extent. Rotary converters are largely used for changing alternating currents

to direct for the operation of street railways, electrolytic plants, etc. These machines are often called *rotary transformers*, but the term *converter* is now most generally applied.

SINGLE-PHASE CONVERTERS.

50. Suppose an ordinary ring armature to be revolved in a two-pole field as shown in Fig. 31; a continuous E. M. F. will be generated and a continuous current obtained by attaching a circuit to the brushes *a*, *a'*. If, instead of the commutator, two collector rings were attached to opposite points of the winding, an alternating current would be

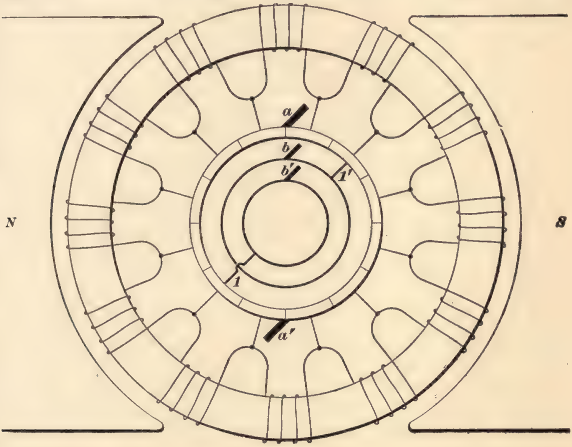


FIG. 31.

obtained in a circuit connected to *b*, *b'*. If the machine be equipped with both commutator and collector rings, the armature may be revolved by means of a direct current led in at the brushes *a*, *a'*, thus running it as a motor instead of its being driven by a belt. The conductors on the revolving armature will be cutting lines of force just as much as

they were when the machine was driven by a belt, therefore an alternating current will be obtained from the rings b, b'. In other words, the machine acts as a converter, changing the direct current into a single-phase alternating current. If the operation be reversed and the machine run as a synchronous alternating-current motor, the alternating current will be transformed to direct current.

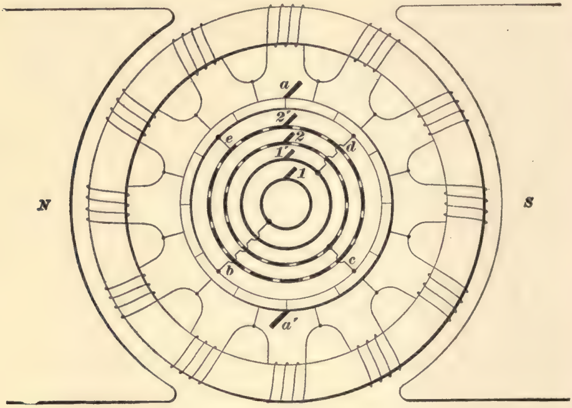


FIG. 32.

51. In the above single-phase rotary converter it is evident that the maximum value of the alternating E. M. F. occurs when the points *1*, *1'* to which the rings are connected are directly under the brushes a, a'; that is, the maximum value of the alternating E. M. F. is equal to the continuous E. M. F. For example, if the continuous E. M. F. were 100 volts, the *effective* volts on the alternating-current side would be $\frac{100}{\sqrt{2}} = 70.7$ volts. Therefore, if E is the alternating voltage and V the direct, we may write for a single-phase rotary converter

$$E = .707\ V. \qquad \textbf{(3.)}$$

TWO-PHASE CONVERTERS.

52. By connecting four equidistant points of the winding *b*, *c*, *d*, and *e*, Fig. 32, to four collector rings, we would have a two-pole two-phase, or quarter-phase, converter. In this case we would have two pairs of lines leading from the brushes *1*, *1'*, *2*, *2'*, and the E. M. F. between *1* and *1'* or between *2* and *2'* would be given by formula **3.**

THREE-PHASE CONVERTERS.

53. By connecting three equidistant points as shown at *b*, *c*, and *d*, Fig. 33, a three-phase converter is obtained.

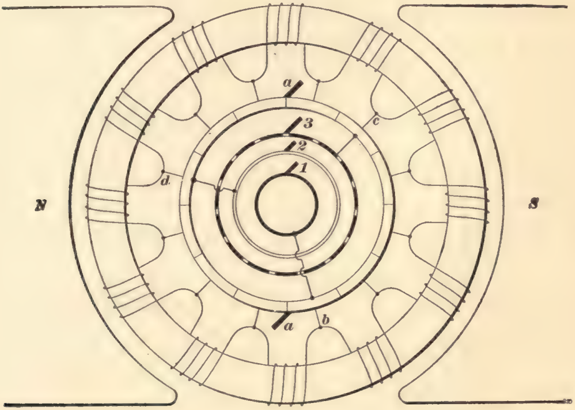


FIG. 33.

Since all direct-current armatures have closed-circuit windings, it follows that the connections on the alternating-current side of a three-phase rotary converter are always Δ, the Y connection not being possible. If E be the effective voltage between the lines on the alternating side of a

three-phase rotary converter and V the voltage of the continuous-current side,

$$E = .612\ V. \qquad \textbf{(4.)}$$

If such a converter were supplied with a direct current at 100 volts pressure, an alternating current at 61.2 volts would be obtained; and if it were desired to obtain a 100-volt direct current from an alternating current, the alternating side would have to be supplied at a pressure of 61.2 volts.

54. Rotary converters are nearly always of the two-phase or three-phase types and are used for changing alternating currents to direct currents. A multiphase rotary used in this way runs as a synchronous motor, hence its speed is practically constant. The student should note that in the rotary converters just shown, the ratio of transformation is fixed, and in order to raise or lower the E. M. F. of the direct-current side, the E. M. F. of the alternating-current side must also be raised or lowered. This is usually accomplished either by means of potential regulators or by providing the transformers which supply the rotary with secondary coils split up into a number of sections which may be cut in or out. The direct-current voltage can also be changed within certain limits by changing the field excitation of the rotary.

If ratios of transformation differing greatly from those given were required, it would not be possible to use an armature having a single winding for both the alternating-current and the direct-current sides of the machine. In such cases, it would be necessary to use either a machine with two distinct armature windings or else a motor-generator set. It is, however, usually possible to get any desired direct E. M. F. from the alternating by transforming the alternating current to such a voltage that when delivered to the rotary transformer, it will be changed to a direct current of the desired pressure. For example, suppose it were desired to transform alternating current at 2,000 volts to direct current at 500 volts suitable for operating a street

railway. We will suppose that a three-phase rotary transformer is used. Then it follows from formula **4** that the alternating current must be supplied to the machine at a pressure of $E = .612\ V = .612 \times 500 = 306$ volts. The alternating current would, therefore, be first sent through static transformers so wound as to reduce the pressure from 2,000 to 306 volts, and the secondary coils of these transformers would be connected to the alternating-current side of the rotary.

MULTIPOLAR ROTARY CONVERTERS.

55. The windings shown in Figs. 31, 32, and 33 give the connections for two-pole machines, but rotary converters

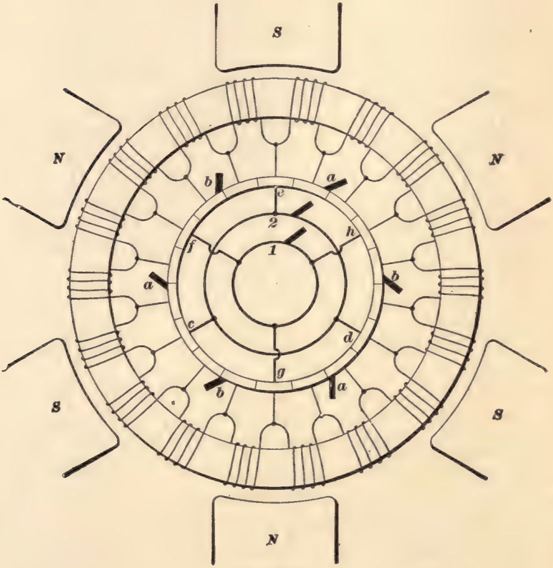


FIG. 34.

are nearly always made multipolar in order to reduce the speed of rotation. In the single-phase machine shown in Fig. 31, it was necessary to have only one connection to each ring; in a multipolar machine it is necessary to have as many connections to each ring as there are pairs of poles on the machine. Fig. 34 shows the connections for

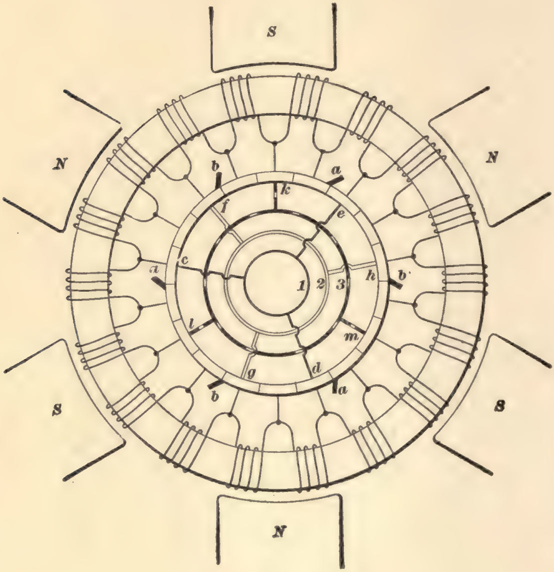


FIG. 35.

a six-pole single-phase rotary. Here the ring *1* is connected to the points *g*, *h*, and *f*, while *2* is connected at *c*, *d*, and *e*, these points being the equivalent of 180° apart. If only two connections were made, as in Fig. 31, the whole of the winding would not be utilized. Fig. 35 represents the same armature connected up as a three-phase rotary.

Here each of the three rings has three connections, as before, and these connections are the equivalent of 120° apart. For example, the angular distance from k to e is one-third the distance from north pole to north pole, which represents 360 degrees. Such a winding would, therefore, have the three connections c, d, e for ring *1*; f, g, h for ring *2*; and k, l, m for ring *3*, there being *as many connections for each ring as there are pairs of poles.*

56. Fig. 36 shows the construction of a modern three-phase rotary converter. The three collector rings are seen

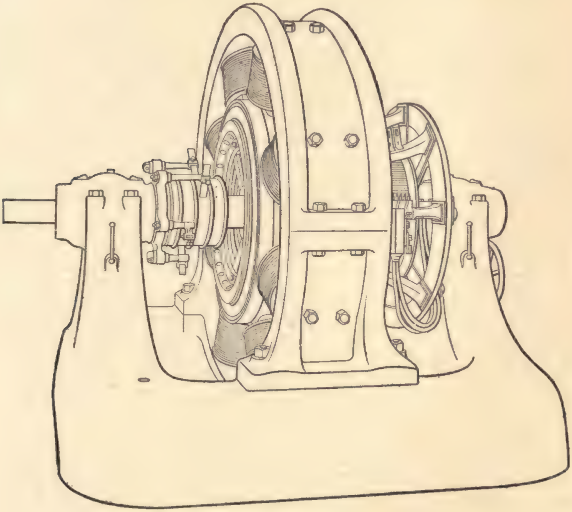


FIG. 36.

at the left-hand end of the machine and the commutator is shown at the right. Like alternators, rotary converters are built for a large range of output and frequency.

ALTERNATORS WITH CLOSED-CIRCUIT ARMATURES.

57. In all that has been said relating to armature windings for alternators we have considered the open-circuit style of winding only. This style of winding, as already pointed out, is used more than the closed-circuit type, because it allows the generation of a higher E. M. F. than the latter with a given number of armature conductors. Alternators are, however, frequently provided with closed-circuit windings. For example, the rotary converter, outside of the addition of the commutator, is practically an alternator and could be run as such. This machine has a closed-circuit winding, the same as a continuous-current dynamo, and a number of taps are simply brought out to the collector rings.

In these machines the armature is provided with a regular closed-circuit winding that is generally about the same as those described in connection with armature windings for multipolar direct-current dynamos. Instead, however, of attaching a commutator as there described, the winding is tapped at two or more equidistant points and the terminals brought to collector rings. For example, in Fig. 37 the circle *1–2–3–4* represents the closed-circuit winding tapped at the four points *1*, *2*, *3*, *4*. The terminals *1'*, *3'*, *2'*, *4'* connect to four collector rings. The current obtained from *1'*, *3'* will differ in phase by 90° from that in *2'*, *4'*, so that this arrangement would be suitable for a two-phase alternator.

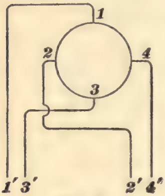


FIG. 37.

In Fig. 37 the winding is supposed to be used in a two-pole field, so that the tapping points are at right angles to each other. The style of winding and connection shown in Fig. 37 is one that has been used very extensively by the Westinghouse Company for their two-phase alternators. If it is desired to operate a two-phase three-wire system from such a machine, three of the collector rings, or taps, are used, as, for example, *1'*, *3'*, *2'*. It is evident that no two of the

taps could be connected together without short-circuiting a portion of the armature. If a three-wire two-phase system were operated from lines *1'*, *3'*, *2'*, one phase would be between *1'* and *2'* and the other between *3'* and *2'*. Also, if the E. M. F. between *1'* and *3'*, i. e., the E. M. F. per phase with the four-wire arrangement were E, then the E. M. F. between *1'* and *2'*, or the E. M. F. per phase in the second case, would be $\frac{E}{1.414}$. If a three-phase two-pole machine were required, the closed-circuit winding would be tapped at three equidistant points.

ELECTRIC TRANSMISSION.

(PART 1.)

INTRODUCTORY.

1. Electric transmission may be defined as the transferring of power from one point to another by means of electricity. The power so transmitted may be used for any of the numerous applications to which electricity is now adapted, such as operating motors, lights, electrolytic plants, etc. The distance over which the power is transmitted may vary from a few feet, as in factories, to several miles, as in some of the modern long-distance transmission plants.

2. A power-transmission system consists of three essential parts: (*a*) The station containing the necessary dynamos and prime movers for generating the electricity; (*b*) the line for carrying the current to the distant point; and (*c*) the various receiving devices by means of which the power is utilized.

3. Electric transmission may be carried out either by using the direct current, the alternating current, or a combination of the two. Generally speaking, in cases where the transmission is fairly short, the direct current is used. When the distance is long, it is best to use the alternating current. In cases where the distance is long and where alternating current is not well adapted to the operation of the receiving devices, the current transmitted over the line is alternating, and this current is changed to direct current at the distant end and there distributed, thus forming a

combination of the two systems. The special applications of electric transmission to railway and lighting work will be taken up later in connection with those branches of the subject; for the present, the object is only to bring out a few important points relating to the subject of electric-power transmission generally. Practically, all electric-power-transmission plants, whether direct or alternating, use constant-potential dynamos, i. e., the dynamos in the power station maintain a nearly constant pressure and the current varies with the load.

4. Power transmission is extensively used in connection with water-powers that would in many cases be of little use on account of their being located away from railways or commercial centers. It is also coming into use largely in factories to replace long lines of shafting and numerous belts, which are wasteful of power. Its most extensive use, however, is in connection with the operation of street railways, where the power is transmitted from the central station to the cars scattered over the line. The style of apparatus used will depend altogether on the special kind of work that the plant is to do, and the type best adapted for a given service will be taken up when the different transmission systems are treated later.

THE POWER STATION.

5. The **power station** is a building intended for the reception of all the apparatus necessary for the economical and reliable generation of power and its transformation into electric energy for transmission to the points where it is to be used. It is usual, where ground is not expensive, to build a one-story structure, providing room for offices, stores, machinery, etc., or a separate building may be erected for offices and stores.

6. Prime Movers.—At present there are three kinds of prime movers in common use for electric-power-transmission

work. These are **steam engines, waterwheels,** and **gas** or **oil engines.** Steam is used more as a source of power than either water or gas, but the development of long-distance power transmission has greatly increased the use of water-power, and the gas engine is rapidly gaining in favor.

STEAM PLANTS.

7. Engines.—The type of engine that is most suitable for a power station depends entirely on the size of the system and on the general requirements of the service. The closest speed regulation under widely varying loads is obtained with high-speed, automatic cut-off engines, and this class is, therefore, particularly suitable for small electric railways and lighting plants. A little consideration will show that such systems may furnish extremes of load at very short intervals; for if there were on a small railroad only one car in service, the station load would be zero (or simply the friction of the moving machinery) when the car was at rest and a maximum when it was starting on a heavy grade. Again, in a small lighting plant, a large proportion of the lamps may be turned on or off at once, thus causing great fluctuations in the central-station load. In general it may be stated that the larger the system, the nearer will the load approach a constant normal value. In very large systems the load will be a maximum at certain hours of the day or night, and will gradually fall to a minimum at other hours. For such an installation, it is best to use low-speed Corliss engines and run them with condensers, if water for this purpose is readily available. In large plants it is now customary to use large, low-speed Corliss engines, either of the horizontal or vertical type, the latter being preferable where the floor space is limited.

8. Boilers.—The boilers in most general use are those carrying the water in tubes and called water-tube boilers, the reason for the preference being that they steam rapidly and will therefore respond quickly to extra demands made

upon them. Many stations are, nevertheless, equipped with return-tubular boilers, which give entire satisfaction. For steady work, this type is preferred by many station managers, as the steam pressure in a water-tube boiler will fall as easily as it rises, if the boiler is not properly fired; on the score of safety, however, water-tube boilers are doubtless superior. When space is very limited, vertical boilers are sometimes put in.

Mechanical stokers are much used when it is desired to burn fine coal, and in such cases generally prove economical; also, economizers may be placed in the chimney, close to the boilers, their function being to warm the feedwater by means of the waste furnace gases. The boiler room should be designed with a special view to the expeditious handling of coal and ashes with a minimum of labor. To accomplish this, it is well to deliver the coal from a railroad car and unload directly into bunkers, from which it can readily be supplied to the several boilers. These bunkers should have storage capacity for at least 15 days, unless there is another large supply easily accessible. A subway may be built beneath the ash-pits, and these may be fitted with doors to open downwards, through which the ashes can be swept into a small car running on a track beneath. This is a refinement of practice perhaps justifiable only in the case of very large plants.

Provision must be made for a plentiful supply of water. It is not always well to trust entirely to city mains, although this source is usually reliable. When the station is not located near running water, it may be found advisable to sink a well, from which water may be pumped into a tank and the water from the mains used only in cases of emergency.

9. Steam Piping.—The steam piping for the station should receive the most careful thought, as it is of the greatest importance, and on its correct design will depend the prime requisite of successful operation, which is, that under no circumstances should there be failure of the current supply to the lines. Some of the engines in many power stations

must be kept turning all the time. The simplest means of connection is to supply steam to each engine from an independent boiler, but the objection to this is that, in the event of trouble with any boiler necessitating repairs, its engine would also be put out of service. To overcome this difficulty, the boilers might all be connected together by a steam main, as at *m*, Fig. 1; this is provided with stop

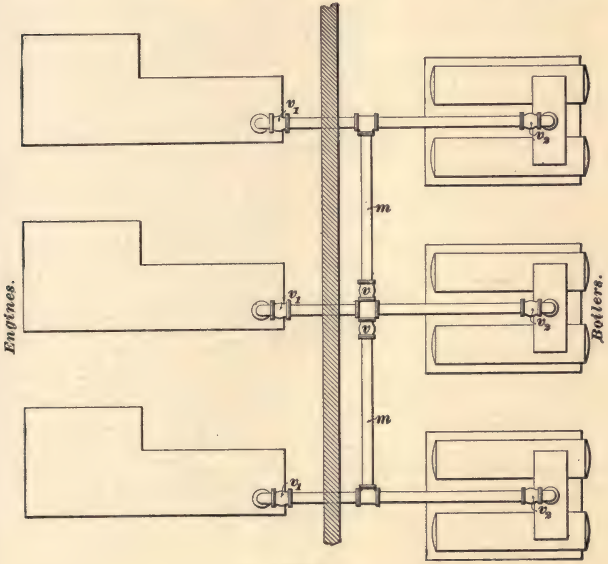


FIG. 1.

valves v, v, which, with the valves v_1 at the engines and those at the boilers v_2, afford a means of disconnecting any engine or boiler without affecting the rest of the plant. This system is the cheapest reliable one, but is not the safest, because there is no duplication of pipes, and if one were to burst or otherwise get out of order, the engine or boiler connected to it would be put out of service.

10. There are two principal methods of installing a duplicate system, and they differ at first sight only in point of size of pipes. A diagram of the arrangement is shown in Fig. 2. Two mains m, m_1 run the whole length of the boiler room, being connected on one side with leaders to the boilers a, b, c, and on the other with leaders passing through

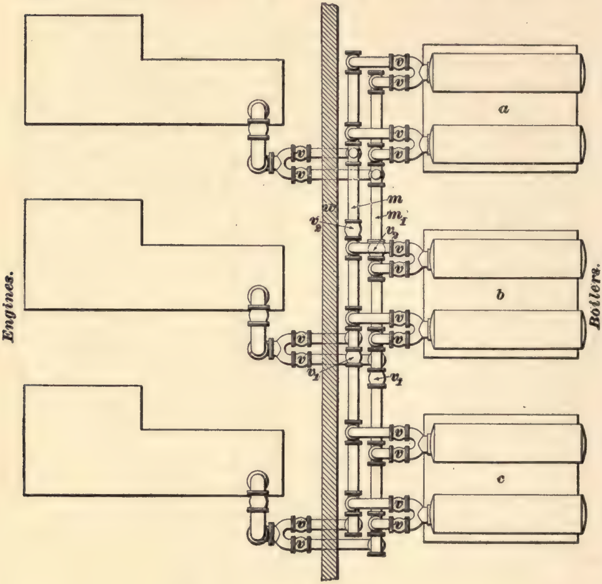


FIG. 2.

the fire-wall w to the engines. These connecting pipes, it will be seen, are all in pairs, and start from the two mains; each one is provided with a stop valve v at the end, and every pair terminates in a cast-iron **Y**, both at the drum of the boiler and at the engine. This system, therefore, provides a double path for the steam between any engine and any boiler, and renders almost wholly improbable a suspension

of operation due to accident to the steam-power generating plant. The difference alluded to between the two methods of duplicating is that in one system, pipes are provided of such size that one set alone will carry the steam for the engines and the duplicate piping is held as a reserve, while in the other, the pipes are of smaller size and are in use all the time, their combined area of cross-section being necessary for delivering the steam at the determined pressure. The first system is used quite frequently, but has, nevertheless, many disadvantages. It is impossible to keep the valves connecting with the reserve piping closed so tightly that no steam will leak past, and there is always a pressure indicated on the gauge. The exposure of all this surface to condensation, even though protected by nonconducting covering, entails a continual waste of energy, and the drips always have to be left open to prevent the pipes filling up with water. Then, the first cost of such a system is considerably higher than if the smaller pipes were used, and repairs are more expensive. It may also happen that an engineer will habitually use one set of pipes alone for a long period, and when an accident compels him to close this set, he finds that the valves of the auxiliary piping have become seated through rust or deposits from the water and are immovable, and a shut-down is the result. With the second system, the exposed surface of pipes is less, both sides are in service continually, and if an accident should occur to one branch, the remaining branch will furnish steam until a repair is accomplished. There would be, through the one pipe, a greater drop in pressure, but this would easily be remedied by closing the valves v_{11}, v_1 or v_2, v_2 communicating with the rest of the system and running one boiler at a higher pressure for a time. Other methods of piping are sometimes resorted to, but these two, as illustrated in Figs. 1 and 2, will generally be found to satisfy the conditions of simple connections on the one hand or the more expensive but more reliable construction on the other. Generally speaking, it may be said that the use of duplicate steam piping is not as popular as it once was.

Some of the most modern power plants do not use duplicate piping, but take great care to see that everything connected with the single piping is of the best possible quality and has a large factor of safety. If proper care is taken in selecting the material and installing the piping system, there should be little need of putting it up in duplicate.

11. General Arrangement.—The general arrangement of a steam plant depends very largely on the style of machinery used. In any event, the boiler room and engine room should be separated from each other by a fire-wall with fireproof communicating doors. The complete separation of these departments will prevent accumulation of dust on the dynamos and engines due to the handling of coal and ashes. In some cases, where ground space is limited, the engines are placed on one floor and the dynamos on the floor above, the power being transmitted by means of belts. One method uses individual driving from each engine to one or two dynamos located directly above, but a better one is to make use of countershafts on the engine or dynamo floor, or both. These countershafts are divided into sections and fitted with friction pulleys in such a way as to permit of any desired combination of engines and dynamos, an arrangement best calculated to ensure uninterrupted service. A simple example of such an installation is shown in Fig. 3, the lower view being an elevation. The engines are on the lower floor and the countershaft *c* on the upper floor, directly

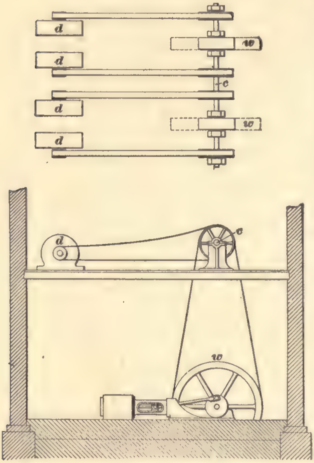


FIG. 3.

above the flywheels and connected by belting to the dynamos *d*. Two engines are indicated, their flywheels *w*, *w* being dotted in the plan.

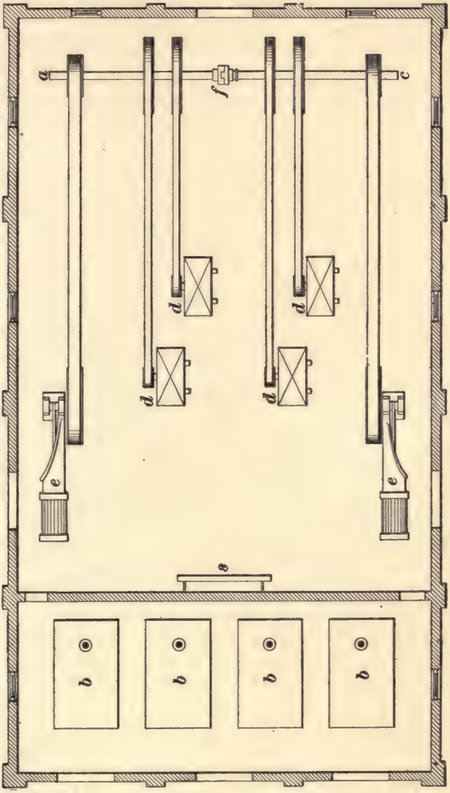


FIG. 4.

12. Another plan showing the general arrangement of machinery and boilers for a small station is given in Fig. 4. The engines *e*, *e* are placed near the walls, allowing the

whole center of the room for the dynamos *d*. At one end is the countershaft *a c*, which may be divided and fitted with a coupling at *f* for disconnecting one-half of the generating plant when the load is light. The switchboard *s* should be near the dynamos, but not so close as to be liable to injury from a broken belt. Beyond the fire-wall are the boilers *b*, arranged so that the distance from them to the engine shall be as small as possible, to avoid condensation of steam in the pipes.

13. The two foregoing plans using belts and countershafts were largely used at one time, but the countershaft in electric-power plants is rapidly going out of existence. The countershaft not only involves a certain waste of power, but it also necessitates the use of a large amount of belting. Now that dynamos are built to run at lower speeds than formerly and are made in larger sizes, the need of a countershaft does not exist to the extent it once did. In medium-sized plants it is now customary either to belt each dynamo directly to its engine or, what is still better, to have the armature of the dynamo mounted directly on the shaft of the engine. This last method of direct driving is becoming almost universal in all large, modern plants. The dynamos used for direct connection must, of course, run slower than those driven by belt, because their speed must suit that of the engine. This means that a direct-connected dynamo must be larger, heavier, and more expensive for the same output than the belt-driven machine. The first cost of the direct-connected machine is, therefore, greater than the belt-driven one. This extra expense is to a certain extent offset by the absence of belting and the decreased wear and tear on the machinery due to the low speed of operation. A great saving in floor space is also gained by using direct-connected generating sets, and this saving of space is an important item in large cities, where ground is very expensive. For small plants, where the first cost must be kept down and where economy of space is not necessary, belted units are still installed in many cases.

14. Fig. 5 shows the arrangement of a typical modern central station designed for a large output. The generators *G* are of the multipolar type and are driven directly by the large vertical engines. An electric traveling crane *E* runs the whole length of the dynamo room, so that parts of

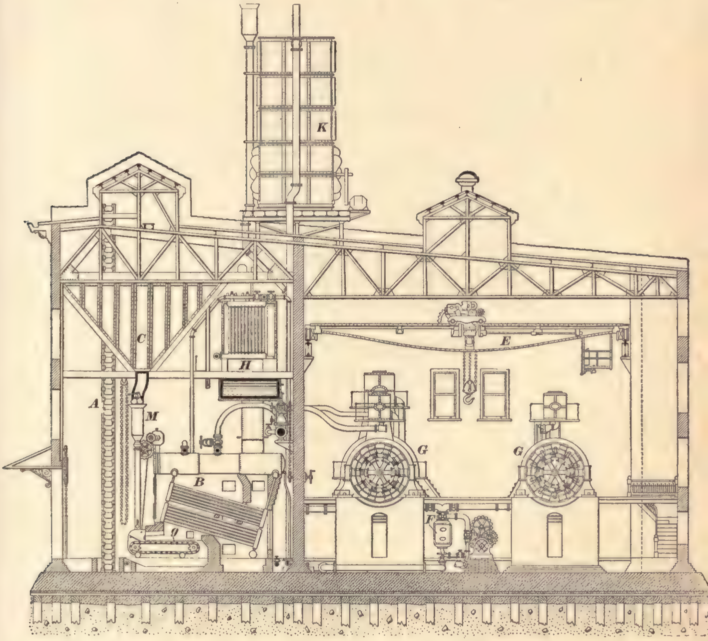


FIG. 5.

the engines or dynamos may be easily handled in case repairs are necessary. The condenser *F* is situated in the basement, and in this case both the air pump and circulating pump are driven by electric motors. The boiler room is situated on the left and is separated from the engine room by a fireproof wall. The boilers *B* are of the water-tube

type. The hot furnace gases pass through the economizer *H* on their way to the stack, and thus heat up the feedwater before it enters the boilers. Coal is delivered to the hopper *C* by means of the conveyer *A*, and from *C* it is fed to the boilers by means of the chute *M* and the automatic stoker *g*. All the power required for the stokers, coal-handling machinery, etc. is supplied by electric motors. The hot water from the condenser is conveyed to a tower *K*, where it is allowed to fall and come in contact with a current of air set up by fans. The water is cooled by this means, and may be used over again for condensing purposes. The general tendency is towards a centralization of electric light and power plants, while the former practice was to use a number of smaller plants, each located near the district to be supplied. The consequence is that city plants are continually increasing in size, and the plant shown in Fig. 5 is a very fair example of one of these more recent installations.

WATER-POWER PLANTS.

15. The general arrangement of a water-power plant must be made to fit the particular water-power that is used to run the plant. In most cases the station is situated at or near the stream supplying the power, and the type of waterwheel used must be adapted to the head or fall of water obtainable. For electric-power-transmission work, two kinds of waterwheels are in common use, *turbines* and *tangential* or *impulse* wheels. The former are used in by far the greater number of cases, but the latter are especially adapted for use in connection with the high heads met with in mountainous districts. Where waterwheels are used in connection with electric-power-transmission plants, they are frequently coupled directly to the dynamo. The wheel itself in such cases may be of the vertical or horizontal type, but the latter is by far the more common, because it permits the use of ordinary types of dynamo. The most notable example of vertical turbines direct-connected to dynamos is the Niagara plant, part of which is shown in

section in Fig. 6. The water from the canal *C* flows into the head-race *H* and thence to the turbines *T* through the penstocks *P*. The wheels are placed at the bottom of the

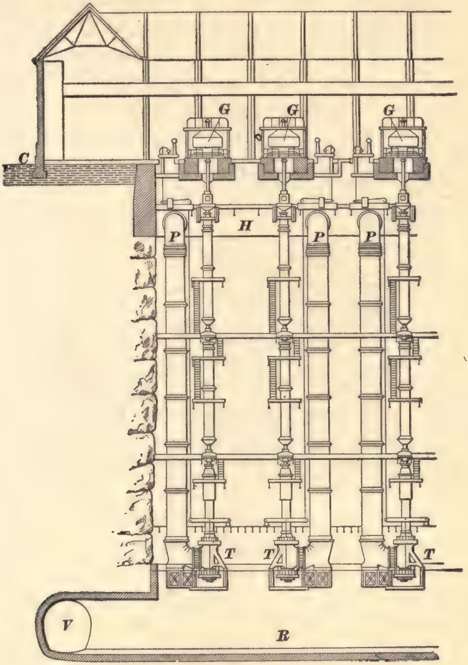


FIG. 6.

wheel pit and the revolving fields of the generators *G* are carried by the vertical shaft. The water, after leaving the wheels, drops into the tail race *R* and passes off through the tunnel *V* to a point below the falls.

16. Horizontal Turbines.—Fig. 7 shows a typical arrangement of a horizontal turbine, or rather a pair of turbines. In many cases these turbines are direct-connected

to the dynamos, an arrangement that is becoming very common in water-power-transmission plants, where the conditions are suited to this method of operation. It is very compact, and there is no belting or gearing of any kind. Sometimes the turbine and dynamo are both mounted on the same base, while in other plants the turbines are arranged in

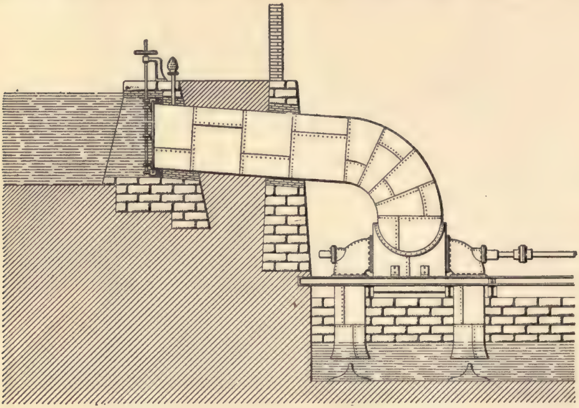


FIG. 7.

one room, and the machines are driven by the shafts which extend through into a separate dynamo room. When the dynamos have to run at a high speed, it is necessary, of course, to use belting. In a great many plants the dynamos are driven by vertical turbines through belting or gearing, but the horizontal type is gradually replacing the vertical type for this kind of work.

GAS-ENGINE PLANTS.

17. Gas engines and oil engines have in the past been used to but a very limited extent in America in connection with electric-power-transmission plants. One of the objections to such engines was that they did not give a steady

speed, and, hence, caused fluctuations in voltage. This has been overcome in the later types of engine, and the gas engine will no doubt come largely into use in connection with electrical work. Power can be obtained from coal cheaper by converting the coal into gas and utilizing this gas in a gas engine than by burning the coal under a boiler and using a steam engine. In a gas-engine plant, the boilers would be replaced by gas producers and the steam engines by gas engines. In some few cases natural gas is available, but generally a gas-producing plant would have to be provided. The general arrangement of such a station would be practically the same as that already described for a steam plant.

LINE CONDUCTORS.

18. Before going on with a consideration of the principles involved in electric-power transmission, it will be well to take up briefly the properties of the metals used as conductors. The line wire is, in the vast majority of cases, of copper. Aluminum is now coming into use for this purpose, and in the future it may replace copper for some lines of work. Iron or steel is seldom used for a line conductor, because its resistance is too high. There is one particular case, however, in which it is largely used as a return conductor, and that is in connection with electric railways, where the current is led back to the power house through the rails.

COPPER CONDUCTORS.

19. Bare and Insulated Wires.—Line conductors are usually in the form of copper wire of round cross-section whenever the conductor is of moderate size. For conductors of large cross-section, stranded cables are used, made up of a number of strands of small wire twisted together. This construction makes the conductor flexible and easy to handle. When these wires or cables are strung in the air, they are

usually insulated by a covering that consists of two or three braids of cotton, soaked in a weather-proof compound composed largely of pitch or asphalt. If a better insulation is required, the wire is first covered with a layer of rubber and

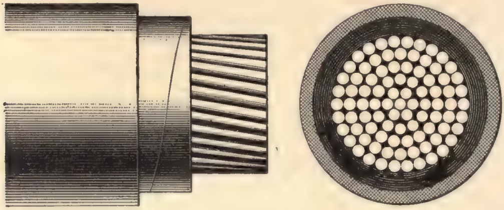


FIG. 8.

the braid applied over it. For underground work, the conductor is first insulated with rubber or paper soaked in compound and the whole covered with a lead sheath to keep out

FIG. 9.

moisture. Fig. 8 shows a stranded cable for underground work provided with an insulating layer of paper and a lead sheath. Fig. 9 shows an ordinary triple-braid weather-proof

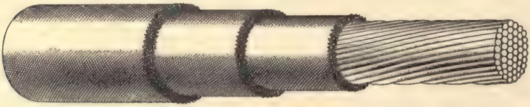


FIG. 10.

overhead line wire, and Fig. 10 a weather-proof overhead cable. When the pressure used on the line is very high, say 10,000 volts or over, bare wires are often used, because the ordinary weather-proof insulation is of little or no protection

against such pressures and only gives a false appearance of security. The practice for such lines is, therefore, to use bare wire and to insulate this wire thoroughly by means of specially designed insulators.

WIRE GAUGES.

20. Various standards or **wire gauges** have been adopted by different manufacturers, but the safest and best way is always to express the diameter of a wire in *mils*, or thousandths of an inch, and its area of cross-section in *circular mils*. The American, or Brown & Sharpe, gauge is used almost exclusively in America in connection with electrical work, but it is always well to give the diameter of the wire as well as its gauge number, so as to avoid any possibility of mistake.

21. Circular Measure.—The diameter of a wire is usually expressed either as a decimal part of an inch or in terms of a unit called the **mil.** A mil is equal to one-thousandth of an inch, i. e., 1 mil = .001 inch. For example, if a wire were two-hundredths of an inch in diameter (.020″), it would have a diameter of 20 mils.

22. A **circular mil** is a unit of area used in expressing the area of cross-section of wires. It will be seen later that a simple relation exists between the diameter of a wire and its area of cross-section expressed in circular mils, so that if either one of these quantities is known the other can be readily obtained. If the diameter of a circle is d inches, its area in square inches is $d^2 \times .7854$. If d is expressed in mils, the area, calculated in the same manner, will be given in square mils.

23. The square inch is not a convenient unit to use for expressing the area of cross-section of wires because, in the first place, it is too large, and, in the second place, the quantity .7854 makes the calculations awkward to perform rapidly. In order to get around these difficulties, the

circular mil is used for expressing the area of cross-section. The circular mil is the area enclosed by a circle of which the diameter is one mil, or one one-thousandth of an inch. Its area is therefore $(\frac{1}{1000})^2 \times .7854$, or .0000007854 square inch. Suppose now that we have a wire the diameter of which is d mils. Its area in square inches will be $\left(\frac{d}{1{,}000}\right)^2 \times .7854$. But we have seen above that the area of 1 circular mil is .0000007854 square inch, hence the number of circular mils that there must be in a wire of diameter d mils is $\dfrac{\left(\frac{d}{1{,}000}\right)^2 \times .7854}{(\frac{1}{1000})^2 \times .7854} = d^2$; or, *the number of circular mils cross-section of a wire is equal to the square of its diameter expressed in mils.* If, then, we know the diameter of any wire, we can at once obtain its area in circular mils by expressing the diameter in mils and squaring it.

EXAMPLE 1.—A round wire has a diameter of .036 inch; what is its diameter in mils and its area in circular mils?

SOLUTION.—Since 1 mil = .001 inch, the diameter will be 36 mils. Circular mils $= d^2 = 36^2 = 1{,}296$. Ans.

EXAMPLE 2.—What would be the area of the above wire in square mils?

SOLUTION.—Area in square mils $= d^2 \times .7854$, where d is the diameter in mils. Hence, square mils $= d^2 \times .7854 = 1{,}296 \times .7854 = 1{,}018$, nearly. Ans.

EXAMPLE 3.—Find the area in circular mils of a round copper rod $\frac{1}{4}$ inch in diameter.

SOLUTION.— $\frac{1}{4}$ inch = .250 inch = 250 mils; hence, area in circular mils $= 250^2 = 62{,}500$. Ans.

EXAMPLE 4.—Find the area in square mils of a $\frac{1}{2}$-inch square, copper bar.

SOLUTION.— $\frac{1}{2}$ inch = .500 inch = 500 mils. Area in square mils $= 500 \times 500 = 250{,}000$. Ans.

EXAMPLE 5.—A round rod has an area of 125,000 circular mils; what is its diameter in mils?

SOLUTION. — We have area in circular mils $= d^2$, or $d = \sqrt{\text{area in circular mils}} = \sqrt{125{,}000} = 354$ mils, nearly, or about .354 in. Ans.

TABLE I.

DIFFERENT STANDARDS FOR WIRE GAUGE.

Dimensions of Wires in Decimal Parts of an Inch.

Number of Wire Gauge.	American, or Brown & Sharpe.	Birmingham, or Stubs.	Washburn & Moen M'f'g Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	G. W. Prentiss, Holyoke, Mass.	Old English, From Brass Mfrs'. List.	British Standard.	Number of Wire Gauge.
000000			.4600					000000
00000			.4300	.4500				00000
0000	.460000	.454	.3930	.4000				0000
000	.409640	.425	.3620	.3600	.3586			000
00	.364800	.380	.3310	.3300	.3282			00
0	.324860	.340	.3070	.3050	.2994			0
1	.289300	.300	2830	.2850	.2777			1
2	.257630	.284	.2630	.2650	.2591			2
3	.229420	.259	.2440	.2450	.2401			3
4	.204310	.238	.2250	.2250	.2230		.2320	4
5	.181940	.220	.2070	.2050	.2047		.2120	5
6	.162020	.203	.1920	.1900	.1885		.1920	6
7	.144280	.180	.1770	.1750	.1758		.1760	7
8	.128490	.165	.1620	.1600	.1605		.1600	8
9	.114430	.148	.1480	.1450	.1471		.1440	9
10	.101890	.134	.1350	.1300	.1351		.1280	10
11	.090742	.120	.1200	.1175	.1205		.1160	11
12	.080808	.109	.1050	.1050	.1065		.1040	12
13	.071961	.095	.0920	.0925	.0928		.0920	13
14	.064084	.083	.0800	.0800	.0816	.08300	.0800	14
15	.057068	.072	.0720	.0700	.0726	.07200	.0720	15
16	.050820	.065	.0630	.0610	.0627	.06500	.0640	16
17	.045257	.058	.0540	.0525	.0546	.05800	.0560	17
18	.040303	.049	.0470	.0450	.0478	.04900	.0480	18
19	.035890	.042	.0410	.0400	.0411	.04000	.0400	19
20	.031961	.035	.0350	.0350	.0351	.03500	.0360	20
21	.028462	.032	.0320	.0310	.0321	.03150	.0320	21
22	.025347	.028	.0280	.0280	.0290	.02950	.0280	22
23	.022571	.025	.0250	.0250	.0261	.02700	.0240	23
24	.020100	.022	.0230	.0225	.0231	.02500	.0220	24
25	.017900	.020	.0200	.0200	.0212	.02300	.0200	25
26	.015940	.018	.0180	.0180	.0194	.02050	.0180	26
27	.014195	.016	.0170	.0170	.0182	.01875	.0164	27
28	.012641	.014	.0160	.0160	.0170	.01650	.0148	28
29	011257	.013	.0150	.0150	.0163	.01550	.0136	29
30	.010025	.012	.0140	.0140	.0156	.01375	.0124	30
31	008928	.010	.0135	.0130	.0146	.01225	.0116	31
32	.007950	.009	.0130	.0120	.0136	.01125	.0108	32
33	007080	.008	.0110	.0110	.0130	.01025	.0100	33
34	006304	.007	.0100	.0100	.0118	.00950	.0092	34
35	.005614	.005	.0095	.0095	.0109	.00900	.0084	35
36	.005000	.004	.0090	.0090	.0100	.00750	.0076	36
37	004453		.0085	.0085	.0095	.00650	.0068	37
38	.003965		.0080	.0080	.0090	.00575	.0060	38
39	.003531		.0075	.0075	.0083	.00500	.0052	39
40	.003144		.0070	.0070	.0078	.00450	.0048	40
41							.0044	41
42							.0040	42

TABLE II.

DIMENSIONS, WEIGHT, ETC. OF BARE COPPER WIRE.

American, or B. & S., Gauge.

Gauge No.—B. & S.	Diameter in Mils, or $\frac{1}{1000}$ Inch.	Area in Circular Mils. C. M. = d^2.	Area in Square Inches. Area = $\frac{d^2}{1,000,000} \times .7854$.	Weights—Specific Gravity, 8.89.				Resistance at 68° F., in International Ohms, Based on Matthiessen's Standard.				
								Ohms per 1,000 Feet.		Ohms per Mile.		
	d	d^2		Pounds per 1,000 Feet.	Pounds per Mile.	Feet per Pound.	Ohms per Pound, Annealed.	Pure Annealed.	Hard Drawn.	Pure Annealed.	Hard Drawn.	Feet per Ohm, Annealed.
0000	460.000	211,600.00	.1661900000	640.50000	3,381.400	1.561	.00007639	.04893	.050036	.25835	.26419	20,440.000
000	409.640	167,805.00	.1317900000	508.00000	2,682.200	1.969	.00012150	.06170	.063094	.32577	.33314	16,210.000
00	364.800	133,079.40	.1045200000	402.80000	2,126.800	2.482	.00019310	.07780	.079558	.41079	.42007	12,850.000
0	324.865	105,534.50	.0828870000	319.50000	1,686.900	3.130	.00030710	.09811	.100330	.51802	.52973	10,190.000
1	289.300	83,694.20	.0657320000	253.30000	1,337.200	3.947	.00048830	.12370	.126490	.65314	.66790	8,083.000
2	257.630	66,373.00	.0521280000	200.90000	1.060.600	4.977	.00077650	.15600	.159530	.82368	.84239	6,410.000
3	229.420	52,634.00	.0413390000	159.30000	841.090	6.276	.00123500	.19670	.201140	1.03860	1.06210	5,084.000
4	204.310	41,742.00	.0327840000	126.40000	667.390	7.914	.00196300	.24800	.253610	1.30940	1.33920	4,031.000
5	181.940	33,102.00	.0259990000	100.20000	529.060	9.980	.00312200	.31280	.319870	1.65160	1.68890	3,197.000
6	162.020	26,250.50	.0206180000	79.46000	419.550	12.580	.00496300	.39440	.403320	2.08250	2.12950	2,535.000
7	144.280	20,816.00	.0163510000	63.02000	332.750	15.870	.00789200	.49730	.508540	2.62580	2.68500	2,011.000
8	128.490	16,509.00	.0129670000	49.98000	263.890	20.010	.01255000	.62710	.641270	3.31110	3.38590	1,595.000
9	114.430	13,094.00	.0102830000	39.63000	209.240	25.230	.01995000	.79080	.808760	4.17530	4.27690	1,265.000
10	101.890	10,381.00	.0081548000	31.43000	165.950	31.820	.03173000	.99720	1.019900	5.26570	5.38480	1,003.000
11	90.742	8,234.00	.0064656000	24.93000	131.630	40.120	.05045000	1.25700	1.285400	6.63690	6.78690	795.300
12	80.808	6,529.90	.0051287000	19.77000	104.390	50.590	.08022000	1.58600	1.621800	8.37410	8.56330	630.700

13	71.961	5,178.40	.0040672000	15.68000	82.791	63.790	.12760000	1.99900	2.044300	10.55500	10.79400	500.100
14	64.084	4,106.80	.0032254000	12.43000	76.191	80.440	.20280000	2.52100	2.577900	13.31100	13.61200	396.600
15	57.068	3,256.70	.0025579000	9.85800	52.050	101.400	.32250000	3.17900	3.250800	16.78500	17.16500	314.500
16	50.820	2,582.90	.0020285000	7.81800	41.277	127.900	.51280000	4.00900	4.099600	21.16800	21.64600	249.400
17	45.257	2,048.20	.0016087000	6.20000	32.736	161.300	.81530000	5.05500	5.169200	26.69100	27.29400	197.800
18	40.303	1,624.30	.0012757000	4.91700	25.960	203.400	1.29600000	6.37400	6.518300	33.65500	34.41600	156.900
19	35.890	1,288.10	.0010117000	3.89900	20.595	256.500	2.06100000	8.03800	8.219600	42.44100	43.40000	124.400
20	31.961	1,021.50	.0008023100	3.09200	16.324	323.400	3.27800000	10.14000	10.372000	53.53900	54.74900	98.660
21	28.462	810.10	.0006362600	2.45200	12.946	407.800	5.21200000	12.78000		67.47900		78.240
22	25.347	642.40	.0005045700	1.94500	10.268	514.200	8.28700000	16.12000		85.11400		62.050
23	22.571	509.45	.0004001500	1.54200	8.142	648.400	13.18000000	20.32000		107.29000		49.210
24	20.100	404.01	.0003173300	1.22300	6.457	817.600	20.95000000	25.63000		135.53000		39.020
25	17.900	320.40	.0002516600	.96990	5.121	1,031.000	33.32000000	32.31000		170.59000		30.950
26	15.940	254.10	.0001995800	.76920	4.061	1,300.000	52.97000000	40.75000		215.16000		24.540
27	14.195	201.50	.0001582700	.61000	3.221	1,639.000	84.23000000	51.38000		271.29000		19.460
28	12.641	159.79	.0001255100	.48370	2.554	2,067.000	133.90000000	64.79000		242.09000		15.430
29	11.257	126.72	.0000995360	.38360	2.025	2,607.000	213.00000000	81.70000		431.37000		12.240
30	10.025	100.50	.0000789360	.30420	1.606	3,287.000	338.60000000	103.00000		543.84000		9.707
31	8.928	79.70	.0000625990	.24130	1.274	4,145.000	538.40000000	129.90000		685.87000		7.698
32	7.950	63.21	.0000496430	.19130	1.010	5,227.000	856.20000000	163.80000		864.87000		6.105
33	7.080	50.13	.0000393680	.15170	.801	6,591.000	1,361.00000000	206.60000		1,090.80000		4.841
34	6.305	39.75	.0000312210	.12030	.635	8,311.000	2,165.00000000	260.50000		1,375.50000		3.839
35	5.615	31.52	.0000247590	.09543	.504	10,480.000	3,441.00000000	328.40000		1,734.00000		3.045
36	5.000	25.00	.0000196350	.07568	.400	13,210.000	5,473.00000000	414.20000		2,187.00000		2.414
37	4.453	19.83	.0000155740	.06001	.317	16,660.000	8,702.00000000	522.20000		2,757.30000		1.915
38	3.965	15.72	.0000123450	.04759	.251	21,010.000	13,870.00000000	658.50000		3,476.80000		1.519
39	3.531	12.47	.0000097923	.03774	.199	26,500.000	22,000.00000000	830.40000		4,384.50000		1.204
40	3.145	9.89	.0000077634	.02993	.158	33,410.000	34,980.00000000	1,047.00000		5,528.20000		.955

24. The Brown & Sharpe Gauge.—This gauge is usually termed the **B. & S. gauge,** and is generally used in the United States for designating the sizes of copper wire. The sizes of wire as given by this gauge range from No. 0000, which has a diameter of .460 inch, to No. 40, which has a diameter of .0031 inch; the higher the gauge number the smaller the wire. The rule by which the sizes of wire increase as the gauge number diminishes is a very simple one. If we take any given gauge number as a basis of comparison, a wire three numbers higher will have very nearly half the cross-section, and one three numbers lower will have twice the cross-section. For example, a No. 4 wire has twice the cross-section of a No. 7, and a No. 10 has one-half the cross-section of a No. 7.

25. Another point that is useful to bear in mind in reference to the B. & S. gauge is that a No. 10 wire has a diameter of very nearly $\frac{1}{10}$ inch and that its resistance per 1,000 feet is almost exactly 1 ohm. By remembering the foregoing properties of this gauge and the figures relating to the No. 10 wire, rough calculations may be made as to the diameter and resistance of other sizes. It is better, however, to consult a good wire table than attempt to burden the mind with a lot of rules. A number of other gauges are in use, and as the student may sometimes find wires given in terms of these, Table I is given, showing the diameters of wires according to the different gauges.

26. Table II gives the properties of copper wire according to the B. &. S. gauge. Sizes smaller than No. 14 are seldom used for electric transmission, but the complete table is given for reference, as the small sizes are largely used in connection with the windings of various types of electrical apparatus. The resistances as given in this table are based on the standard used by Matthiessen in his experiments; if the purity of the copper is not up to this standard, its resistance may run somewhat higher than the values given in the table, but the difference will not be very great,

because copper wire, as now manufactured, is remarkably pure. All the weights given are, of course, for bare copper wire.

27. Table III gives the approximate weights of weather-proof line wire, such as is used for ordinary outside lines.

TABLE III.

APPROXIMATE WEIGHTS OF WEATHER-PROOF WIRE.

(*American Electrical Works.*)

TRIPLE-BRAIDED INSULATION.

Size.	Feet per Pound.	Pounds per 1,000 Feet.	Pounds per Mile.	Carrying Capacity, Amperes, National Board Fire Underwriters.
4–0	1.34	742	3,920	312
3–0	1.64	609	3,215	262
2–0	2.05	487	2,570	220
0	2.59	386	2,040	185
1	3.25	308	1,625	156
2	4.10	244	1,289	131
3	5.15	194	1,025	110
4	6.26	160	845	92
5	7.46	134	710	77
6	9.00	111	585	65
8	13.00	73	385	46
10	20.00	50	265	32
12	29.00	35	182	23
14	38.00	26	137	16
16	48.00	21	113	8
18	67.00	15	81	5

TABLE III.—*Continued.*

DOUBLE-BRAIDED INSULATION.

Size.	Feet per Pound.	Pounds per 1,000 Feet.	Pounds per Mile.	Carrying Capacity, Amperes, National Board Fire Underwriters.
4–0	1.40	711	3,754	312
3–0	1.75	570	3,010	262
2–0	2.29	436	2,300	220
0	2.81	355	1,875	185
1	3.56	281	1,482	156
2	4.49	223	1,175	131
3	5.45	184	969	110
4	6.82	147	774	92
5	9.10	110	580	77
6	10.35	97	510	65
8	15.52	64	340	46
10	22.00	45	237	32
12	40.00	25	132	23
14	56.00	18	95	16
16	76.00	13	69	8
18	100.00	10	53	5

28. Table IV gives the approximate dimensions of stranded insulated weather-proof cables for overhead work. The area of cross-section of such cables is always designated as so many circular mils, and not by gauge number. In fact, any conductor larger than No. 0000 is usually designated by its area in circular mils. Cables such as those given in Table IV are extensively used for street-railway feeders or for any other purpose requiring a large conductor.

ALUMINUM CONDUCTORS.

29. Mention has already been made of the fact that aluminum is being used for electrical conductors, because this metal can now be sold at a figure low enough to

TABLE IV.

STANDARD WEATHER-PROOF FEED-WIRE.

(*Roebling's.*)

Circular Mils.	Outside Diameters. Inches.	Weights. Pounds. 1,000 Feet.	Weights. Pounds. Mile.	Approximate Length on Reels. Feet.	Carrying Capacity, National Board Fire Underwriters.
1,000,000	$1\frac{1}{2}$	3,550	18,744	800	1,000
900,000	$1\frac{13}{32}$	3,215	16,975	800	920
800,000	$1\frac{11}{32}$	2,880	15,206	850	840
750,000	$1\frac{5}{16}$	2,713	14,325	850	
700,000	$1\frac{9}{32}$	2,545	13,438	900	760
650,000	$1\frac{1}{4}$	2,378	12,556	900	
600,000	$1\frac{7}{32}$	2,210	11,668	1,000	680
550,000	$1\frac{3}{16}$	2,043	10,787	1,200	
500,000	$1\frac{1}{8}$	1,875	9,900	1,320	590
450,000	$1\frac{3}{32}$	1,703	8,992	1,400	
400,000	$1\frac{1}{16}$	1,530	8,078	1,450	500
350,000	1	1,358	7,170	1,500	
300,000	$\frac{15}{16}$	1,185	6,257	1,600	400
250,000	$\frac{29}{32}$	1,012	5,343	1,600	

compete with copper. Its conductivity is only about 62 per cent. that of copper, so that for a conductor of the same resistance a larger cross-section is required. Aluminum is, however, so much lighter than copper that the larger cross-section can be used and still compete with the latter metal, although the cost per pound of the aluminum may be considerably higher. Line-construction work is somewhat easier with the lighter aluminum cables than with copper

cables. Mechanical joints have been devised for connecting together lengths of aluminum cable. A comparison of some of the properties of aluminum and copper is given in Table V.

TABLE V.

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM.

Properties.	Aluminum.	Copper.
Conductivity (for equal sizes)	.61 to .63	1.
Weight (for equal sizes)	.33	1.
Weight (for equal length and resistance)	.47	1.
Ratio of prices per pound in order that the total cost of either material will be the same (for equal length and resistance)	2.13	1.
Ordinary price ratios (for equal length and resistance)	.85 to .9	1.
Temperature coefficient, per degree F.	.002138	.002155
Resistance of mil-foot (20° C.)	18.73	10.05
Specific gravity	2.5 to 2.68	8.89 to 8.93
Breaking strength (wires of equivalent conductivity)	1.	1.
Tensile strength (pounds per square inch, hard drawn)	20,000 to 35,000	20,000 to 60,000
Coefficient of expansion per degree F.	.0000128	.0000093

IRON WIRE.

30. Iron wire is used largely for telegraph and telephone work, but it is seldom employed in connection with electric transmission because of its high resistance. The approximate value of the resistance per mile of a good quality of iron wire may be determined from the formula

$$R = \frac{360,000}{d^2}, \qquad (1.)$$

where d = diameter of wire in mils.

TABLE VI.

DIMENSIONS AND RESISTANCE OF IRON WIRE.

Number B. W. G.	Diameter in Mils = d.	Area in Circular Mils = d^2.	Weight in Pounds.		Breaking Strengths in Pounds.		Resistance per Mile at 68° F.		
			1,000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	115,600	304.0	1,607	4,821	9,079	2.93	3.42	4.05
1	300	90,000	237.0	1,251	3,753	7,068	3.76	4.40	5.20
2	284	80,656	212.0	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.0	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.0	787	2,361	4,449	5.97	6.99	8.26
5	220	48,400	127.0	673	2,019	3,801	4.99	8.18	9.66
6	203	41,209	109.0	573	1,719	3,237	8.21	9.60	11.35
7	180	32,400	85.0	450	1,350	2,545	10.44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14.53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31.0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	125	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	29.08	57.44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.70
17	58	3,364	8.9	47	141	264	100.50	120.40	139.00
18	49	2,401	6.3	33	99	189	140.80	164.80	194.80

For steel wire, which is often used in place of iron wire, this formula becomes approximately

$$R = \frac{470,000}{d^2}. \qquad (2.)$$

31. The various grades of iron wire on the market are termed "Extra Best Best," "Best Best," and "Best." A steel wire is also used, which is cheaper and of higher resistance than iron. It has an advantage, however, of possessing greater tensile strength. It should not be used except on short lines or in special cases where it is desirable to

TABLE VII.

GERMAN-SILVER WIRE.

(Roebling's.)

Number B. & S. Gauge.	Resistance per 1,000 Feet. International Ohms.		Maximum Current Carrying Capacity in Amperes. 18% wire.
	18%.	30%.	
6	7.20	11.21	
7	9.12	14.18	
8	11.54	17.95	
9	14.55	22.63	
10	18.18	28.28	8.5
11	22.84	35.53	5.4
12	28.81	44.82	4.6
13	36.48	56.75	3.8
14	46.17	71.82	3.2
15	58.21	90.55	2.7
16	72.72	113.12	2.3
17	93.40	145.29	1.9
18	118.20	183.87	1.65
19	145.94	227.02	1.21
20	184.68	287.28	.99
21	232.92	362.32	.88
22	295.38	459.48	.66
23	370.26	575.96	.55
24	468.18	728.28	.488
25	590.22	918.12	.434
26	748.08	1,163.68	.385
27	937.98	1,459.08	.343
28	1,191.24	1,853.04	
29	1,481.22	2,304.12	
30	1,891.80	2,942.80	
31	2,388.60	3,715.60	
32	2,955.60	4 597.60	
33	3,751.20	5,835.20	
34	4,764.60	7,411.60	
35	6,031.80	9,382.80	
36	7,565.40	11,768.40	

have great tensile strength. Table VI gives the weight, resistance, etc. of iron wire according to the Birmingham wire gauge, which is most commonly used in connection with iron wire.

GERMAN-SILVER WIRE.

32. German-silver wire is used principally in resistance boxes or electrical instruments where a high resistance is required. The resistance of this wire varies greatly according to the materials and methods of manufacture used. It is an alloy of copper, nickel, and zinc, and has a resistance anywhere from 18 to 28 times that of copper. Its resistance changes only to a small extent with changes in temperature, a feature of value in connection with rheostats and resistance boxes. Table VII gives some of the properties of German-silver wire containing 18 or 30 per cent. of nickel.

POWER TRANSMISSION BY DIRECT CURRENT.

33. Up to within a comparatively recent date, electric transmission for power purposes was carried out by means of the direct current, alternating current being used when the power was required for lighting purposes only. Later, however, alternating-current motors came into use, and at the present time, large transmission systems use alternating current both for light and power. We will first take up the use of direct current and see what conditions are necessary in order that power may be transmitted to the best advantage.

34. Dynamos and Motors Used.—Direct-current dynamos may be either of the constant-current or the constant-potential type. There are but very few power-transmission systems operated by constant-current dynamos, so few that it is not worth while considering such systems. Practically

all the current is distributed at constant potential and, in America, compound-wound dynamos are generally used. The motors used in connection with such constant-potential systems are generally of the shunt type, if used for ordinary stationary work, such as driving machinery. If used for railway work, hoisting, mine haulage, etc., they are of the series type. For some kinds of special work, such as running printing presses, elevators, etc., compound-wound motors are used, but such motors are few in number compared with the others.

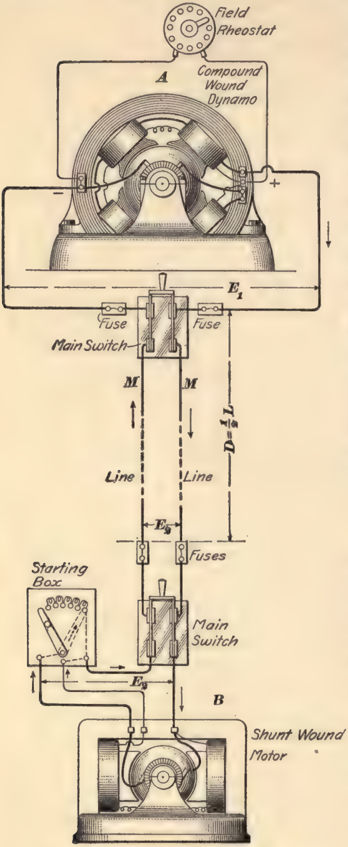


FIG. 11.

35. Simple Power-Transmission System. About the simplest possible system of electric-power transmission is that shown in Fig. 11. Here we have a compound-wound dynamo *A* driven by means of an engine not shown. This dynamo sends a current through the motor *B* by means of the lines *M*, *M*. The dynamo is driven at a constant speed and its series winding

is adjusted so that the pressure at the terminals of the dynamo rises slightly as the current increases, due to the increase of the load on the motor. This slight rise in voltage is to make up for the loss in pressure in the line, as will be explained later. The pressure at the motor as a whole, however, remains nearly constant, no matter what load the motor may be carrying, but the current supplied increases as the load is increased. Of course, lamps could also be operated on the same system, although it is advisable to have separate circuits for the lamps and motors whenever possible, because if the load on the motor fluctuates, it is apt to cause variations in the lights. When both lights and motors are operated, such a system would probably use a pressure of 110 volts at the receiving end of the circuit; if used for power alone, a pressure of 250 or 500 volts would be employed. It should be mentioned that when the **receiving** end of a circuit is spoken of, the end distant from the station is meant, because this is the end where the various devices, such as lamps, motors, etc., receive their current.

36. Lost Power and Line Drop.—In order that a transmission plant may be efficient, the generating apparatus, line, and motors must be efficient. Dynamos and motors of good make are generally satisfactory as regards efficiency, and the question is, how efficient can the line be made? In answer to this, it might be said that the loss of power in the line could be made as small as we please if expense were no consideration. All conductors, no matter how large, offer some resistance to the current and there is bound to be some loss in power. By making the conductor very large we can make the loss small, because the resistance will be low, but a point is soon reached where it pays better to allow a certain amount of power to be lost rather than to further increase the size of the conductor. The pressure necessary to force the current over the line is spoken of in power-transmission work as the **drop** in the line, because this pressure is represented by a falling off in voltage between the dynamo and the distant end of the line.

37. If R is the resistance of the line and C the current flowing, the drop is, from Ohm's law, $e = C R$. The power, in watts, lost in the line is $C R \times C = C^2 R$. The power lost, due to the resistance encountered by the current, reappears in the form of heat. The power generated by the dynamo is equal to the product of the pressure generated by the dynamo and the current flowing; or, if E_1 represents the dynamo pressure, then

$$\text{Watts generated} = W_1 = E_1 \times C. \qquad \textbf{(3.)}$$

The power delivered at the end of the line is equal to the product of the pressure at the end of the line multiplied by the current, or, if E_2 represents the pressure at the distant, or receiving, end, then

$$\text{Watts delivered} = W_2 = E_2 \times C. \qquad \textbf{(4.)}$$

It should be particularly noted at this point that the current C is the same in all parts of the circuit. Thus, in Fig. 11 the same current flows through the motor that flows through the dynamo, unless there is leakage at some point between the lines, and this would not be the case if the lines were properly insulated. What does occur is a drop or loss in pressure between the station and the receiving end, but there is practically no loss in current except, perhaps, in a few cases where the line pressure is exceedingly high or the insulation unusually bad. This point is mentioned here because the mistaken idea that there is a loss of current in the line is a common one.

38. We have already seen that the number of watts lost in the line is given by the equation

$$W = C^2 R.$$

The lost power must also be equal to the difference between the power supplied and the power delivered, or

$$\begin{aligned} W &= W_1 - W_2 \\ &= E_1 C - E_2 C \\ &= C(E_1 - E_2). \end{aligned}$$

$E_1 - E_2$ represents the loss of pressure, or the drop, and it is at once seen that the greater the drop, the greater the loss in power. For example, a 5-per-cent. drop in voltage is equivalent to a 5-per-cent. loss of power in the line.

39. In order to transmit power, we must be willing, then, to put up with a certain amount of loss, or, what is equivalent, with a certain amount of drop in the line. The amount of drop can be made anything we please, depending on the amount of copper we are willing to put into the line. The percentage of drop allowed is seldom lower than 5 per cent. and not often over 15 per cent.; 10 per cent. is a fair average. In cases where the distribution is local, as, for example, in house wiring, the allowable drop from the point where the current enters to the farthest point on the system may be as low as 1 or 2 per cent. If the drop is excessive, the pressure at the end of the line is apt to fluctuate greatly with changes of load and thus render the service bad. In a few special cases there may be conditions that warrant the use of an excessive drop, but in general the above values are the ones commonly met with.

40. When the loss, or drop, in a circuit is given as a percentage, this percentage may refer to the power or voltage at the station end of the line, or the receiving end. For example, suppose we take the case where the percentage loss refers to the power at the station end, and let

E_1 = voltage at dynamo;
E_2 = voltage at end of line;
$\%$ = percentage loss (expressed as a number, not as a decimal);
e = actual number of volts drop in the line.

Then, $$E_1 = \frac{100\,E_2}{100 - \%}. \qquad (5.)$$

And $$e = \frac{100\,E_2}{100 - \%} - E_2. \qquad (6.)$$

EXAMPLE.—The voltage at the end of a lighting circuit is to be 110 and the allowable drop is to be 3 per cent. of the dynamo voltage. (*a*) What will be the dynamo voltage? (*b*) What will be the actual drop in volts in the circuit?

SOLUTION.— (*a*) We have $E_1 = \frac{100 \times 110}{100 - 3} = 113.4$. Ans.

(*b*) The drop $e = \frac{100 \times 110}{100 - 3} - 110 = 3.4$ volts. Ans.

41. It is frequently more convenient to express the loss as a percentage of the power *delivered* at the end of the line. For example, if the voltage at the end of the line were 110, and the loss were to be an amount equivalent to 3 per cent. of *the power delivered*, instead of 3 per cent. of *the power generated*, it would mean that the allowable drop was 3 per cent. of 110, or 3.3 volts, instead of 3.4 volts. Railway generators are commonly spoken of as being adjusted for 10-per-cent. loss when they are so wound as to generate 500 volts at no load and 550 volts at full load; i. e., 50 volts, or 10 per cent., of 500, is allowed as drop in the line, 500 being the voltage at the end of the line. In expressing the loss as a percentage, then, it should be distinctly understood as to whether this percentage refers to the power *generated* or the power *delivered*, otherwise there is liable to be confusion. The best way is to express the drop directly in volts and then there can be no doubt as to what is meant. In what follows, we will, when expressing the loss as a percentage, refer to the power delivered unless it is otherwise specified, as this method is now very generally followed.

LINE CALCULATIONS.

42. Calculations for Two-Wire System.—We are now in a position to look into the method of determining the size of wire necessary for a given case. We will first consider the simple transmission system, shown in Fig. 11. The problem of determining the size of a line wire usually comes up about as follows: Given a certain amount of power to be transmitted over a given distance with a given amount of

loss; also, given the required terminal voltage; determine the size of line wire required. The whole problem of determining the size of line wire simply amounts to estimating the size of wire to give such a resistance that the drop will not exceed the specified amount. All the formulas for this purpose are based on Ohm's law, and are simply this law arranged in a little more convenient form to use. There have been a large number of these formulas devised, each for its own special line of work, and the one that is derived below is given because it is as generally applicable as any.

43. In the first place, if we are given the watts or horsepower to be delivered and are also given the voltage at the end of the line, we can at once determine the current, because

$$C = \frac{W_2}{E_2}, \qquad \textbf{(7.)}$$

in which W_2 is the power delivered. Furthermore, the drop e in the line is known or specified, and since

$$e = CR, \qquad \textbf{(8.)}$$

or

$$R = \frac{e}{C},$$

the resistance R of the line is easily determined.

44. Referring to Fig. 11, we see that the total length L of line through which the current flows is twice the distance from the dynamo to the end of the line. It has already been shown that the resistance of a wire is directly proportional to its length and inversely proportional to the area of its cross-section, and we may then say that

$$R = \frac{K \times L}{A},$$

when K is a constant that depends on the units used for expressing the length L and the area of cross-section A. In practice, it is generally most convenient to have the length L expressed in feet and the area in circular mils. When these units are used, the quantity K is the resistance of 1 **mil-foot**

of wire; i. e., the resistance of 1 foot of wire $\frac{1}{1000}$ inch in diameter. If the area of cross-section of the wire were only 1 circular mil, it is evident that the resistance of L feet of it would be $K \times L$, and if the area of the wire were A circular mils, its resistance would be $\frac{K \times L}{A}$.

The resistance of 1 mil-foot of copper wire such as is used for line work may be taken as 10.8 ohms. This resistance will, of course, vary with the temperature and also with the quality of the wire used, but the above value is close enough for ordinary line calculations. We may then use the following formula for calculating the resistance of any line:

$$R = \frac{10.8 \times L}{A}, \qquad \textbf{(9.)}$$

where R = resistance in ohms;
L = length of line in feet (total length, both ways);
A = area of cross-section in circular mils.

45. What we usually wish to obtain is the area of the wire required for the transmission, not the resistance, and by combining formulas **8** and **9**, this can be readily done.

We have $$e = CR,$$

but $$R = \frac{10.8 \times L}{A};$$

hence, $$e = \frac{10.8 \times L \times C}{A},$$

or $$A = \frac{10.8 \times L \times C}{e}. \qquad \textbf{(10.)}$$

Expressing this formula in words, we have the required area of cross-section in circular mils

$$= \frac{10.8 \times \text{length of line in feet} \times \text{current in amperes}}{\text{drop in volts}}$$

This rule for determining the size of wire for a given transmission may be written as follows:

Rule.—*Take the continued product of 10.8, the total length of the line in feet, and the current in amperes; divide by the drop in volts, and the result will be the area of cross-section in circular mils.*

46. It will be noticed that the size of wire has been determined by making it of such size that the drop will not exceed the allowable amount. In other words, the drop has been made the determining factor and no attention has been paid to the current-carrying capacity of the wire. If the distance were very short and the drop allowed were large, the size of wire as given by the formula might be such that it would not carry the current without greatly overheating. This is an important consideration where wires are run indoors, because the distances are then short and the rise in temperature of the wire needs to be carefully considered, owing to the fire risk. This point will be taken up in connection with interior wiring. For line work such as we are now considering, the distances are usually so large that the size of wire as determined by the allowable drop is nearly always much larger than would be called for simply to carry the current without becoming hot enough to do damage.

47. The formula given above is also often written in the form

$$A = \frac{21.6 \times D \times C}{e}, \qquad \textbf{(11.)}$$

where D is the distance (one way) from the station to the center where the power is delivered. Evidently, D is only one-half the length of line through which the current flows, i. e., $L = 2D$; hence, we double the constant 10.8 and use 21.6 in the formula.

48. Formulas **10** and **11** may be applied to a large number of cases if care is taken to see that the proper values are substituted in them. The length L or distance D *must always be expressed in feet.* The use of the formula will be illustrated in connection with the following examples:

EXAMPLE 1.—In Fig. 11. the pressure at the receiving end of the line is to be 500 volts, and 40 kilowatts are to be transmitted with a drop of 50 volts. The distance from the station to the end of the line is 3 miles. Calculate the cross-section of wire necessary and give the nearest size B. & S. that will answer.

SOLUTION.— 40 kilowatts = 40,000 watts; hence, current $= \frac{40,000}{500} = 80$ amperes. The distance from the station to the end of the line is 3 miles, but the current has to flow to the end and back again, so that the length of line L through which the current flows is 6 miles, or 31,680 feet. Applying formula **10,** we then have

$$A = \frac{10.8 \times 31,680 \times 80}{50}$$

$$= 547,430 \text{ circular mils, nearly. Ans.}$$

This is considerably larger than any of the B. & S. sizes, so that a stranded cable would be used.

EXAMPLE 2.—It is desired to transmit 20 horsepower over a line ½ mile long with a drop of 10 per cent. of the voltage at the receiving end. The voltage at the end of the line is to be 110. Find the size of wire required.

SOLUTION.— 20 horsepower = 20 × 746 watts, and, hence,

$$\text{Current} = \frac{20 \times 746}{110} = 135.6 \text{ amperes.}$$

The drop is to be 10 per cent. of the voltage at the receiving end; hence,

$$\text{Drop } e = \frac{110 \times 10}{100} = 11 \text{ volts.}$$

The length L is 1 mile, since the distance from the station to the end is ½ mile, and applying formula **10,** we have

$$A = \frac{10.8 \times 5,280 \times 135.6}{11} = 702,950 \text{ circular mils, nearly. Ans.}$$

This also would call for a large cable.

EXAMPLE 3.—Fig. 12 shows a simple transmission system as used in connection with a street railway. The feeder $a c$ runs out from the station and taps into the trolley wire $x y$ at the point c. The pressure between the trolley and track at the point c is to be 500 volts, and the loss *in the feeder* is to be 10 per cent. of the voltage at the car when a current of 60 amperes is being supplied. The current returns through the track, and we will suppose in this case that the resistance of the return circuit is negligible. Required the cross-section of the feeder $a c$.

SOLUTION.—In this case the drop takes place altogether in the wire *a c*, because the resistance of the return circuit through the rails is

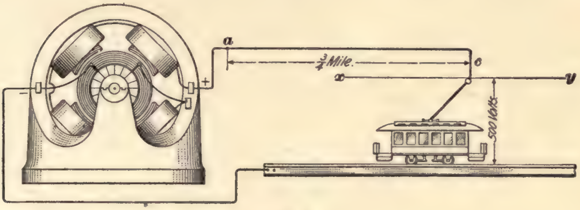


FIG. 12.

taken as zero; hence, the length L used in the formula will be ¾ mile, or 3,960 feet, and not twice this distance, as in the previous examples. The drop in voltage will be

$$e = \frac{500 \times 10}{100} = 50,$$

and since the current is 60 amperes, we have

$$A = \frac{10.8 \times 3,960 \times 60}{50} = 51,322 \text{ circular mils. Ans.}$$

Referring to the wire table, we find that this is nearly a No. 3 B. & S.

49. In making line calculations, it seldom happens that the calculated value will agree exactly with any of the sizes given in the wire table. It is usual in such cases to take the next larger size, unless the smaller size should be considerably nearer the calculated value. Generally, the load operated on a line always tends to increase, because business increases, and it is better to have the line a little large, even if it entails a slightly greater cost when the line is erected.

50. Formula **10** may also be used for determining the drop that will occur on a given line with a given current. In this case the formula is written

$$\text{Volts drop} = e = \frac{10.8 \times L \times C}{A}. \qquad \textbf{(12.)}$$

EXAMPLE.—Power is transmitted over a No. 3 B. & S. line for a distance of 4,000 feet. What will be the drop in the line when a current of 30 amperes is flowing?

SOLUTION.—The length of wire through which the current flows is $2 \times 4,000 = 8,000$ feet. The cross-section of a No. 3 B. & S. wire is 52,634 circular mils; hence,

$$\text{Volts drop} = \frac{10.8 \times 8,000 \times 30}{52,634} = 49.2. \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. A dynamo delivers current to a motor situated 850 yards distant. The current taken by the motor at full load is 30 amperes, and the pressure at the motor is to be 220 volts. The drop in the line is to be 8 per cent. of the voltage at the receiving end. Required (*a*) the drop in volts; (*b*) the size of the wire in circular mils and also the nearest size B. & S.

Ans. $\begin{cases} (a) & \text{17.60 volts.} \\ (b) & \text{93,886 cir. mils., No. 1 wire.} \end{cases}$

2. A current of 40 amperes is transmitted from a station to a point 1 mile distant through a No. 0 B. & S. wire. (*a*) What will be the drop in volts in the wire? (*b*) How many watts will be wasted in the wire?

Ans. $\begin{cases} (a) & 43.2. \\ (b) & 1,728. \end{cases}$

USE OF HIGH PRESSURE.

51. By referring to the first two examples of Art. **48**, it will be noticed that the wire called for is very large, although the amount of power transmitted is not very great nor the distances long. Suppose we have a fixed number of watts W_2 to transmit with a given voltage E_2 at the end of the line; then, the current that must flow through the line is $\frac{W_2}{E_2}$. Also, we have already seen in Art. **37** that the loss in the line is $C^2 R$; i. e., if the current be doubled the loss becomes 4 times as great. If we can double the E. M. F., we will be able to transmit the same amount of power with one-half the current, and, hence, with one-quarter the loss. Or, if we put it the other way, and suppose that our loss is to be a fixed amount, we can, by doubling the pressure and

thereby halving the current, use a wire of 4 times the resistance. For example, suppose we have to transmit 20 kilowatts at a terminal pressure of 500 volts and that the loss in the line is to be limited to 2 kilowatts. The current would be $C = \frac{20000}{500} = 40$ amperes, and $C^2R = 2{,}000$ watts, or $40^2R = 2{,}000$; hence, $R = \frac{2000}{1600} = 1.25$ ohms. Now, suppose that we use a terminal pressure of 1,000 volts instead of 500, and transmit the same amount of power with the same number of watts loss as before. The current will now be $C = \frac{20000}{1000} = 20$ amperes, and $C^2R = 2{,}000$ watts, as before. We will then have $20^2R = 2{,}000$; $R = \frac{2000}{400} = 5$ ohms.

In other words, *for the same amount of loss and for the same amount of power delivered, the allowable resistance of the line is made four times as great by doubling the pressure.* Since the length is supposed to be the same in both cases, this means that doubling the pressure makes the amount of copper required just one-fourth as great. If the pressure were increased threefold, the amount of copper required would be one-ninth as great, other things being kept equal, as before. This may be stated as follows: *For the same amount of power delivered and for the same amount of loss, the amount of copper required for transmission over a given distance varies inversely as the square of the voltage.*

52. Edison Three-Wire System.—From the preceding it will at once be seen that an increase in the voltage results in a large decrease in the amount of copper required. Incandescent lighting was first carried out at a pressure of 110 volts, but this pressure rendered the use of large conductors necessary, and systems were, therefore, brought out that would permit the use of a higher pressure. In street-railway work, a pressure of about 500 volts soon became the standard, because this appeared to be the limit to which the voltage could be pushed for this class of work without danger to life.

The Edison **three-wire system** allows current to be supplied at 110 volts, although the transmission itself is really carried out at 220 volts, and, therefore, results in a large

saving in copper over the old 110-volt system. The three-wire system is shown in Fig. 13. Two compound-wound dynamos *A* and *B* are connected in series across the two lines *d e* and *h k*. Each dynamo generates 110 volts, so that the pressure between the two outside wires is 220 volts,

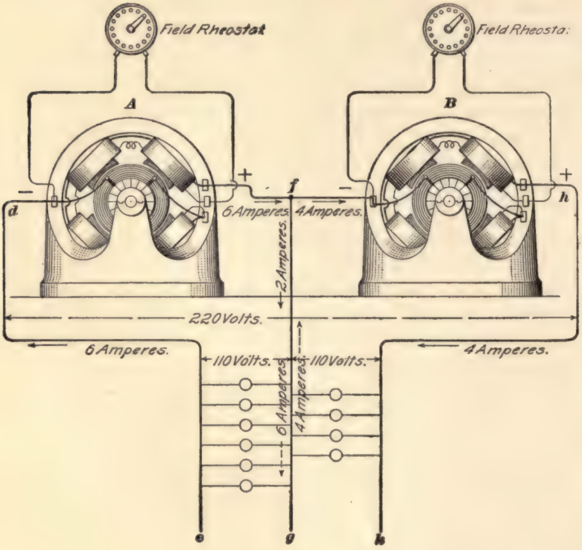


FIG. 13.

because the two machines are connected in series, and their pressures will be added. A third wire, called the *neutral wire*, is connected to the point *f* between the machines, so that between the lines *d e* and *f g* we have a pressure of 110 volts, and between *f g* and *h k* a pressure of 110 volts also.

53. In order to illustrate the action of such a system, we will suppose that we have six 32-candlepower lamps on

one side and four on the other, each lamp taking, say, 1 ampere. A current of 4 amperes will flow from the positive side of B through the line $h\,k$ and through the lamps to the neutral wire. At the same time, a current of 6 amperes will tend to flow out from the positive pole of A over the line $f\,g$ through the left-hand set of lamps and back through $e\,d$, as shown by the arrows. In the neutral wire we have a current of 6 amperes tending to flow in one direction and a current of 4 amperes tending to flow in the other direction, the result being that the actual current is the difference between the two, or 2 amperes, as shown by the full arrow; or, looking at it in another way, we have 4 amperes flowing directly across from $h\,k$ to $d\,e$ and 2 amperes flowing from A through the neutral wire $f\,g$ and back through $e\,d$ to A, thus making 6 amperes in the line $e\,d$. If the currents taken by the two sides were exactly balanced, no current would flow in the neutral wire and we would have what is practically a 220-volt two-wire transmission. In any case, the current in the neutral wire is the difference between the currents in the two sides, and its direction will depend on which side is the more heavily loaded.

54. A three-wire system should always be installed so that the load on the two sides will be as nearly balanced as possible. The simplest way to estimate the size of the conductors is to first calculate the size of the outside wires, treating it as if it were a 220-volt two-wire system. When motors are operated on the three-wire system, they are usually wound for 220 volts and connected across the outside lines. The following example will illustrate the method of calculating the wires for a three-wire transmission:

EXAMPLE.—Two dynamos deliver power over a distance of 1 mile to sixty 32-candlepower lamps, thirty lamps on each side of the circuit, as shown in Fig. 14. A motor that requires a current of 40 amperes is also connected across the outside wires. Each lamp requires a current of 1 ampere, and the pressure at the lamps is to be 110 volts. Calculate the size of wire required for the two outside conductors if the drop in pressure is not to exceed 10 per cent. of the voltage at the end where the power is delivered.

SOLUTION.—The first thing to determine is the current. Thirty lamps are connected on each side and these lamps are connected in multiple, each taking 1 ampere. The current, therefore, in the outside lines due to the lamps is 30 amperes. The motor is connected

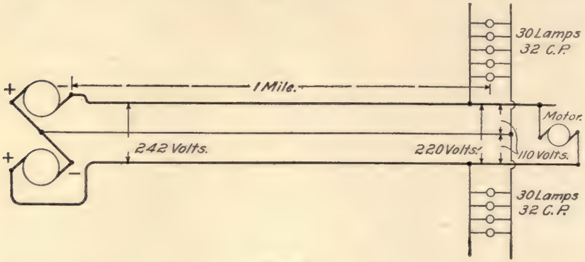


FIG. 14.

directly across the outside lines; hence, the current due to the motor is 40 amperes, and the total current in the outside lines is 70 amperes. The pressure across the outside wires must be 220 volts at the end of the line, because the pressure at the lamps is to be 110. The drop in the outside wires is, therefore,

$$220 \times .10 = 22 \text{ volts.}$$

The length of the outside wires is 2 miles, or 10,560 feet. Applying formula **10,** we have

$$\text{Circular mils} = \frac{10.8 \times 10{,}560 \times 70}{22} = 362{,}880. \quad \text{Ans.}$$

This would require a stranded cable.

55. The neutral wire is often made one-half the cross-section of the outside wires, though practice differs in this respect. It is seldom, however, made less than one-half, and in a number of cases it is made equal in cross-section. Of course, if the load could be kept very nearly balanced at all times, a small neutral wire would be sufficient, but it is impossible to keep the load balanced, and, hence, it is usual to put in a neutral of at least one-half the cross-section of the outside wires. In the above example, a No. 000 wire would probably be large enough for the neutral wire. For distributing mains, when there is much liability to unbalancing, the neutral is made equal in size to the outside wires.

In some cases, three-wire systems are arranged so that they can be changed to a two-wire system by connecting the two outside wires together to form one side of the circuit, the neutral wire constituting the other side. If this is done, the neutral would have to carry double the current in the outside wires and would be made twice as large as the outside wires.

56. Since the outside wires are only $\frac{1}{4}$ the size required for the same power delivered by means of the two-wire 110-volt system with the same percentage of loss, it follows that, even if the neutral wire be made as large as the outside wires, the total amount of copper required is only $\frac{1}{4} + \frac{1}{8}$, or $\frac{3}{8}$ of that required for the two-wire 110-volt system. The amount of copper in the neutral wire is only $\frac{1}{8}$ that which would be required for the two-wire system, because it is only $\frac{1}{4}$ the cross-section and its total length is only $\frac{1}{2}$ that required for the two-wire system.

57. From the preceding it will be seen that the three-wire system of distribution effects a considerable saving in copper, owing to the use of a higher pressure. Three-wire systems operating 220-volt lamps with 440 volts across the outside wires have been introduced with considerable success, thus making a still further reduction in copper. The tendency has naturally been to use as high pressures as possible, but there are grave difficulties in the way of transmitting current at high pressure by means of direct current These difficulties may be classed under the heads (*a*) difficulty of generating direct current at high E. M. F.; and (*b*) difficulty of utilizing direct current at high pressure after it has been generated.

58. Machines for the generation of direct current must be provided with a commutator, and this part of a well-designed machine gives comparatively little trouble if the pressure generated does not exceed 700 or 800 volts. If the pressure is increased beyond this amount, it becomes a difficult matter to make a machine that will operate without sparking. Moreover, in direct-current dynamos, the armature winding has to be divided into a large number of

sections or coils, and the numerous crossings of these coils make it exceedingly difficult to insulate such armatures for high pressures.

59. Even if it were possible to generate high-pressure direct current, it would be difficult to utilize it at the other end on account of the danger to life. About 500 volts is as high as it has been found safe to operate street railways, the consideration of safety setting this limit on the pressure used. Moreover, it is just as difficult to build motors for high-pressure direct current as it is dynamos, and for most purposes the high-pressure current would have to be reduced to low pressure before it could be utilized with safety at the distant end of the line. This transformation could be effected by using a high-voltage motor to drive a low-voltage dynamo. In some cases, these two machines might be combined into one having an armature provided with two windings and two commutators, this armature being arranged so as to revolve in a common field magnet. The high-tension current from the line is here led into one winding through one commutator and drives the machine as a motor. The second set of windings connected to the other commutator cuts across the field and sets up the secondary E. M. F., thus applying current to the low-pressure lines. A machine of this kind is known as a **dynamotor.** It is thus seen that the transformation of direct current from high pressure to low pressure involves the use of what is essentially a high-pressure direct-current motor—a piece of machinery that is liable to give more or less trouble for the reasons already given.

POWER TRANSMISSION BY ALTERNATING CURRENT.

60. The difficulties connected with the generation and utilization of high-tension direct current led engineers to adopt alternating current for places where the power had to be transmitted over considerable distances. At first, alternating current was used for lighting work only, because the

single-phase alternators first introduced were not capable of readily operating motors, although they were quite satisfactory for the operation of incandescent lamps. With the introduction of multiphase alternators along with the induction motor, the use of alternating current for power purposes became very common, and plants using line pressures as high as 40,000 volts, or even higher, are now in use.

61. The alternating current is well adapted for high-pressure work, because not only can it easily be generated, but what is even of greater importance, it can be readily transformed from one pressure to another by means of transformers. The winding of an alternator armature is very simple, no commutator is necessary, and the problem of generating high pressures becomes a comparatively simple one. Alternators with stationary armatures have been successfully built for pressures as high as 10,000 or 12,000 volts. In some cases, the current is generated at a comparatively low pressure and raised by step-up transformers for transmission over the line. At the distant end it is easily lowered, by means of step-down transformers, to any pressure required for the work to which it is to be put.

SINGLE-PHASE TRANSMISSION.

62. The simplest scheme for alternating-current power transmission is that which uses a single-phase dynamo, i. e., a machine that generates a single alternating current. In Fig. 15, *A* represents a simple alternator that generates current at high pressure. This current is transmitted over the line to the distant end, where it is sent through the primary of transformer *B*, which lowers the pressure to an amount suitable for distribution to the lamps *l*. The synchronous motor *M* is operated directly from the line, because it can be wound for a high voltage. If, however, this high pressure about the motor should for any reason be objectionable, step-down transformers could be used. As already

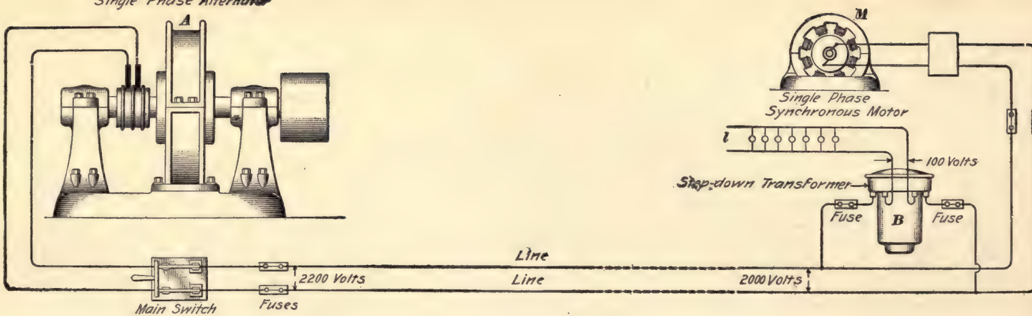

Single Phase
A
M
Single Phase
Synchronous Motor
l
100 Volts
Step-down Transformer
Fuse
B
Fuse
Line
2200 Volts
Line
2000 Volts
Main Switch
Fuses

FIG. 15.

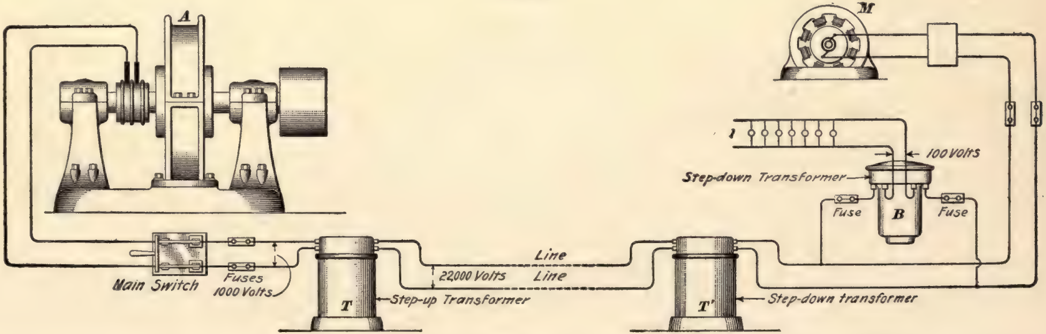
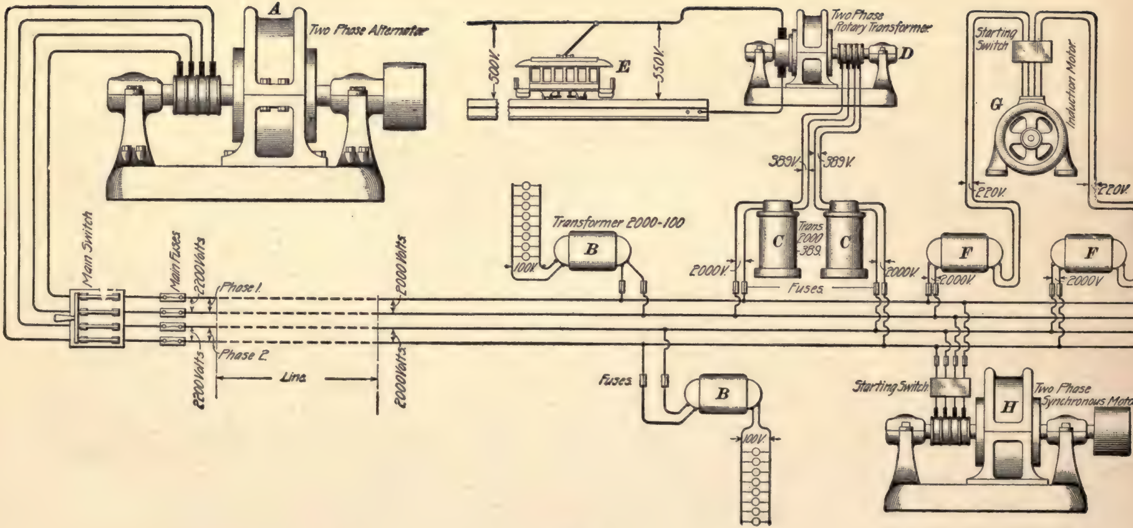

A
M
l
100 Volts
Step-down Transformer
Fuse
B
Fuse
Line
22000 Volts
Line
Main Switch
Fuses
1000 Volts
T
Step-up Transformer
T'
Step-down transformer

FIG. 16.

mentioned, such systems are installed for lighting work almost exclusively, because the single-phase alternating current is not well adapted for the operation of motors. At first a pressure of 1,100 volts at the alternator, or about 1,000 at the end of the line, was commonly used. Later, pressures of 2,200 and 2,000 volts became the ordinary practice. In cases where the distance was very long, step-up transformers were used, as shown in Fig. 16. Here the current from the alternator A is first sent into the primary of the transformer T, which raises the voltage to any required amount, with, of course, a corresponding reduction in current. The alternator might, for example, generate a pressure of 1,000 volts and this pressure be raised to 22,000 for transmission over the line. At the other end, the transformer T' steps down the high line pressure to whatever pressure is suitable for the local distribution. The single-phase alternating-current system is in many respects similar to the two-wire direct-current system, the principal distinguishing feature being the use of transformers.

63. The single-phase system has been used in the past to a limited extent for the operation of synchronous motors. The ordinary single-phase synchronous motor, i. e., a motor constructed in the same way as an alternator, will not start up even if it is not loaded; it has to be brought up to speed from some outside source; this is a great drawback to its use, and the single-phase system is now seldom, if ever, installed where power is to be transmitted for the operation of alternating-current motors of large size. The motor M shown in Fig. 15 is the same in construction as an alternator, but it would have to be provided with some arrangement for bringing it up to speed. This could be done by means of a small single-phase induction motor or by using the exciter of the synchronous motor, running it as a motor from storage batteries. This difficulty of getting single-phase synchronous motors started has kept them from being used to any great extent, and even in those places where they were installed, they are being replaced by multiphase synchronous



A
Two Phase Alternator
E
500V.
550V.
Two Phase
Rotary Transformer
D
Starting
Switch
Induction Motor
G
389V.
389V.
220V.
220V.
Transformer 2000-100
B
100V.
C
Trans.
2000
389
C
2000V.
2000V.
F
F
2000V.
2000V.
Fuses
Main Switch
Main Fuses
2200 Volts
Phase 1.
2000 Volts
Phase 2.
2200 Volts
Line
2000 Volts
Fuses
B
100V.
Starting Switch
H
Two Phase
Synchronous Motor

FIG. 17

motors, which will run up to speed of their own accord when not loaded.

If the amount of power required is not large, say under 10 horsepower, special self-starting single-phase synchronous motors may be used. Induction motors are also made to operate on single-phase circuits by using special starting devices, but in general it may be stated that the single-phase system is not well adapted for motor operation, at least not in those cases where large motors are required.

TWO-PHASE POWER TRANSMISSION.

64. A two-phase alternator delivers two currents differing in phase by 90°, so that when the current in one phase is at its maximum value, the current in the other phase is at zero. The great advantage of the two-phase system over the single-phase is that it allows the operation of rotary-field induction motors and two-phase synchronous motors. Two-phase induction motors will start up under full load. The synchronous motors will not start up under load, but they will run up to synchronous speed if they are not loaded, and the load can be thrown on afterwards, thus avoiding the necessity of any outside means of bringing the machines up to synchronism. Lights may, of course, be operated on the two-phase system equally as well as on the single-phase.

65. Fig. 17 shows a two-phase system. In this case, we have taken the simplest arrangement, where the alternator feeds directly into the line without the use of step-up transformers. If, however, the distance is very long, a pair of step-up transformers could be connected at each end, one in each phase, in a manner similar to that shown in Fig. 16. We have taken the line pressure at 2,000 volts for the sake of illustration. *A* is the alternator supplying the two currents differing in phase by 90° to the four line wires. The only difference between this alternator and a single-phase machine lies in its armature winding and the addition of two more collector rings. *B*, *B* are two transformers supplying lights.

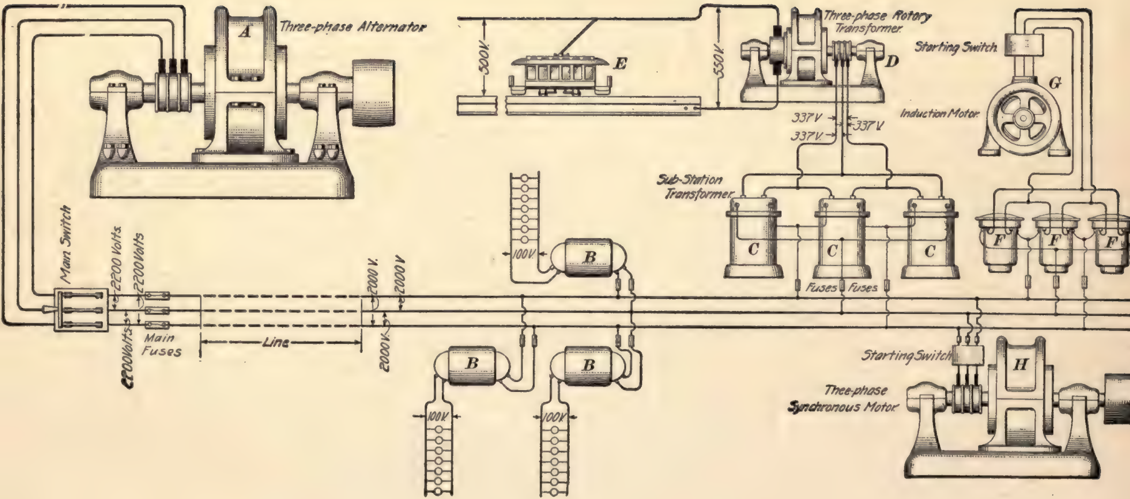
One is connected on Phase No. *1* and the other on Phase No. *2*, so as not to unbalance the load on the alternator. *C*, *C* are two large transformers supplying alternating current at 389 volts to the rotary transformer *D*, which changes it to direct current at 550 volts suitable for operating the street-railway system *E*.

The alternating-current voltage of a two-phase rotary is .707 times the direct-current voltage. If, then, a voltage for operating the street railway is to be 550 volts, the transformers must supply $550 \times .707 = 389$ volts, nearly, to the alternating-current side of the rotary. *F*, *F* are two transformers supplying a two-phase induction motor *G*. As stated above, this type of motor is capable of starting up under full load, and, generally speaking, may be used for all kinds of stationary work for which the ordinary direct-current motor is adapted. *H* shows a two-phase synchronous motor. This is the same in construction as the generator *A*, and it is not necessary to use transformers with it, as it can be constructed for the same voltage as the generator. Synchronous two-phase motors are well adapted for places where power is required in fairly large units and where the motor does not have to be started and stopped frequently. They do not, if properly handled, set up lagging currents; i. e., currents that lag behind the E. M. F., and, hence, are out of phase with the E. M. F. The nature and disadvantages of these lagging currents will be explained more fully in connection with the calculation of lines for alternating current. If synchronous motors and induction motors are operated on the same system as shown in Fig. 17, the lagging current set up by the induction motor may be neutralized by the synchronous motor by increasing the field excitation of the latter to the proper amount. The ordinary method of connecting up transformers on a two-phase circuit is that shown in Fig. 17. Other methods are sometimes used, but these will be taken up later when transformer connections are discussed. In some cases, three line wires only are used, but otherwise the connections are the same as shown in Fig. 17.

THREE-PHASE POWER TRANSMISSION.

66. In the three-phase system, three currents differing in phase by 120°, or one-third a complete cycle, are employed. If the load on all three phases is kept nearly balanced, as it usually is in practice, only three wires are needed. For the same amount of power, line loss, and distance of transmission, the three-phase system requires only three-fourths the amount of copper called for by the single-phase or two-phase system. For this reason, it is often used for the transmission itself, even if the power is generated by means of two-phase alternators. By a special arrangement of transformers, which will be described later, two currents differing in phase by 90° can be transformed into three differing in phase by 120°. Fig. 18 is similar to Fig. 17, except that it is arranged for a three-phase transmission. Lights, rotary transformers, induction motors, and synchronous motors may be operated as previously described, and all the advantages that have been noted with reference to two-phase motors apply equally to three-phase motors. There is little choice between the two-phase systems so far as actual operation is concerned, the chief point in favor of the three-phase system being the saving in line wire.

67. Substations.—In many large transmission systems, it is customary to generate the power in one large central station and distribute it at high pressure to a number of *substations* located at the various distributing centers. At these substations the current is transformed down and passed through rotary transformers, if direct current is necessary, and distributed to the various devices to be operated. This is commonly done in connection with both lighting and street-railway work. If alternating current alone is used, the voltage is merely stepped down by means of large transformers. Perhaps one of the best examples of three-phase transmission is that of the Metropolitan Street Railway Company, of New York. Most of the surface cars in New York City are operated by direct current, at 500 to 600 volts, supplied to the cars by means of conductors placed in a conduit



Three-phase Alternator
A
Main Switch
2200 Volts
2200 Volts
2200 Volts
Main Fuses
Line
2000 V.
2000 V
2000 V.
B
B
B
100 V.
100 V.
100 V.
500 V.
E
550 V.
Three-phase Rotary Transformer
D
337 V
337 V
337 V
Sub-Station Transformer
C
C
C
Fuses
Fuses
Starting Switch
G
Induction Motor
F
F
F
Starting Switch
H
Three-phase Synchronous Motor

FIG. 18

between the rails. Power is generated at one large central station located on the river front, where coal and water are easily supplied. Large 3,500-kilowatt three-phase generators are located in this station. They are of the revolving-field type and are driven directly by large, vertical Corliss engines. These machines generate current at a pressure of 6,600 volts, so that no step-up transformers are used. The current is led from the main station by means of lead-covered underground cables to a number of substations located in different parts of the city. These substations contain the step-down transformers and rotary transformers that are necessary to convert the three-phase current into a direct current of 500 volts suitable for operating the street cars. Each of the rotary transformers is of 900 kilowatts capacity, and before sending the current into rotaries, it is transformed to six phases, as the increased number of phases makes the output of the rotary for a given size of machine greater. Otherwise, the arrangement in the substations is very much the same in principle as that shown at *C* and *D*, Fig. 18. In addition to the rotaries and transformers, such substations are usually provided with two switchboards, one for the high-tension side and the other for the low-tension side, from which the power is distributed. When three-phase rotaries are used, they must be supplied with alternating current at a voltage about .612 times that of the continuous current which they are to supply. For example, in Fig. 18, if the rotary *D* supplies 550 volts direct current, the transformer *C* must supply current at $550 \times .612 = 337$ volts, nearly, to the alternating-current side of the rotaries.

68. Frequencies.—Where motors are operated by alternating current, the frequency used is seldom above 60, although frequencies as high as 125 have been used to a slight extent. A frequency of 60 is very largely used where both lights and motors are operated. Where the current is used for power purposes alone, lower frequencies are common; for example, both the Niagara plant and the plant of

the Metropolitan Street Railway Company, referred to above, use a frequency of 25, as a low frequency is better adapted for the operation of rotary transformers than a high frequency.

TRANSFORMERS AND TRANSFORMER CONNECTIONS.

69. The use of transformers has frequently been mentioned in connection with the preceding articles and their action has already been explained. It will be well, however, to take up here some points relating more particularly to their operation and connections.

70. Transformers vary somewhat as to their construction, but they all have the three essential parts, i. e., the primary and secondary coils or groups of coils and the iron core that serves to carry the magnetic flux through the coils. Their construction also depends to some extent on whether they are to be used outdoors or indoors. Fig. 19 shows a typical transformer for outdoor use mounted on a pole in the usual manner. Where transformers are large, say above 25 or 30 kilowatts capacity, it is not advisable to mount them on poles if it is possible to avoid it. For this reason, large transformers are usually of the indoor type. There is no need of providing weather-proof cases for such transformers, and their construction is very frequently quite open. Most modern transformers for outdoor use are now built so that the case may be filled with oil. This improves the insulation, keeps out moisture, and has considerable effect on the temperature that the transformer attains while in operation. There is bound to be a certain amount of loss in every transformer, owing to the resistance of the coils and the resistance that the core offers to the changing magnetism, i. e., owing to the hysteresis loss. These losses all reappear in the form of heat, and this heat must be gotten rid of by radiation. If there is an air space between the coils and the iron case of the transformer, the heat is conducted away with difficulty:

but if the case is filled with oil, the oil circulates more or less and serves as a conducting medium for carrying the heat from the coils and core to the case, where it is radiated to the surrounding air. Very often, when the transformers are large, they are unable to get rid of the heat by radiation alone, without becoming so hot that there is danger of damaging the insulation, and it is necessary to provide some artificial means for cooling them. This is usually accomplished either by mounting the transformer so that air may be

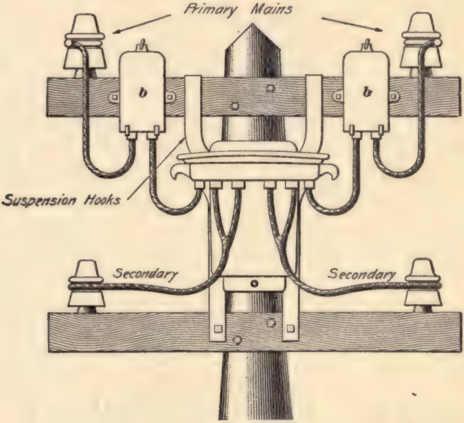


FIG. 19.

circulated through it by means of fans or by immersing the transformer in oil, which is kept cool by water circulating in coiled pipes. As stated above, these precautions are only necessary in the case of large transformers, such as those used in substations. Transformers of ordinary size, such as are placed on poles, are able to get rid of the heat generated without any special cooling devices, because the area exposed to the air is much larger in proportion to the output in the case of a small transformer than in the case of a large transformer.

71. Primary Fuses.—Transformers are operated on constant-potential circuits almost exclusively; hence, if a short circuit occurs on either primary or secondary, there will be a heavy rush of current, which will do damage unless the transformer is instantly disconnected from the circuit. This is accomplished by inserting fuses in the primary between the transformer and the line. These fuses are contained in the fuse boxes *b*, *b*, Fig. 19. They also protect the transformer against overloads, because, if the secondary current is more than it should be, the primary current will also exceed the allowable amount and the fuses will blow. Fuses should be placed in each side of the primary and they should be so mounted that they may be easily replaced by the lineman. In order to accomplish this, nearly all modern primary fuse blocks are made so that the fuse holder may be entirely disconnected from the primary mains when the fuse is being renewed. In other words, the fuse block is made to serve the purpose of a switch as well as a fuse holder. In some cases these primary fuse blocks are double-pole, but when the primary pressure is high, it is better to use two single-pole fuse blocks. Double-pole blocks are not recommended for transformers of larger capacity than 2,500 watts. Above this size it is better to use a single block in each side.

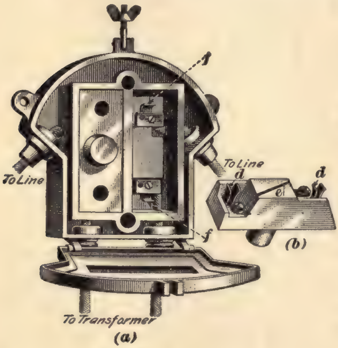


Fig. 20.

72. Fig. 20 (*a*) shows a General Electric double-pole primary switch and fuse block, with one fuse holder (*b*) removed for replacing a fuse. The fuse lies in a deep slot *e* in the porcelain holder (*b*), and is fastened to the clips *d*, *d*. When the holder is in place, the

clips *d*, *d* engage with the terminals *f*, *f*, thus completing the connection to the transformer primary. When a fuse is to be renewed, the porcelain base is pulled out and the lineman can replace the fuse without danger.

73. Fig. 21 shows a single-pole block made by the Stanley Company. In this case, the lid of the iron box is placed at the bottom and the fuse holder *A* is pulled out, thus breaking connection with the terminals *f*, *f*. The fuse *g*

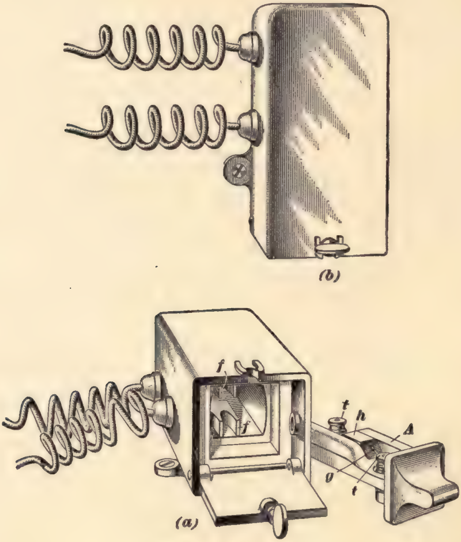


FIG. 21.

runs through a block of wood *h*, thus confining the arc and preventing it from arcing and burning the terminals *t*, *t*. Fig. 21 (*b*) shows the box closed and in the position in which it is placed on the pole. In the General Electric single-pole primary cut-out, the wires enter at the bottom, as shown in

Fig. 19. Where large transformers are operated in substations, automatic switches or circuit-breakers are used instead of fuses to disconnect the transformer from the line in case of a short circuit or overload.

TRANSFORMERS ON SINGLE-PHASE CIRCUITS.

74. Transformers in Parallel.—Transformers may be connected in parallel so as to feed a single circuit, as shown in Fig. 22, but care must be taken in connecting them up, or else a short circuit may result. We will suppose that the two transformers to be connected in parallel are of the same type, so that they will both be wound alike. The primary terminals P_1 and P_3 must be connected to the same main, and P_2 and P_4 to the other main. If this is done, then the secondary terminals *a* and *c*, and *b* and *d* will have the same polarity at the same instant, and these terminals should be connected together, as shown. The external circuit, consisting of lamps or other load, is connected to the secondary mains. Now, it will be noticed that, from the way in which the two secondaries are connected, they oppose each other, and that little or no current will flow until the outside circuit is connected. In practice, it will be found that a small current will flow between the transformers, but this current will not be at all large. Suppose, however, that the secondary terminals should be connected as shown in Fig. 23; it will be seen that the two secondary coils are here connected in series so that the E. M. F.'s generated in them act together to set up a current through the coils,

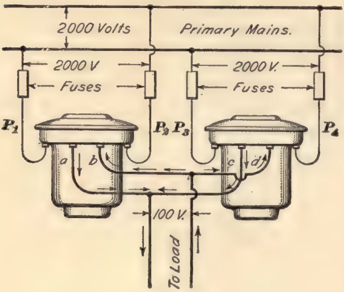


FIG. 22.

thus resulting in a short circuit. In connecting up the secondaries, before making the final connections and before connecting on the circuit, it is always well to make sure that the proper secondary terminals are being connected together. This can be found out by connecting two of them together and then connecting the other two through a piece of small fuse wire or fine copper wire. If the fuse blows, it shows that the connections should be reversed. It is often more convenient to reverse the primary terminals than the secondary, especially if the latter have been joined up permanently. Reversing the primary has, of course, the same effect as reversing the secondary, and it is usually easier to carry out, because the primary connections are light and easy to handle compared with the secondary.

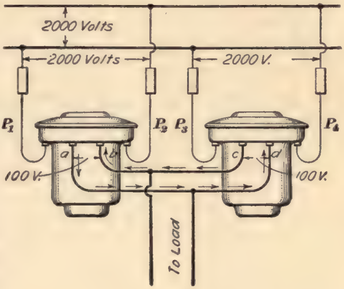


FIG. 23.

75. Generally speaking, it is not advisable to operate several transformers in parallel, or *banked*, as it is sometimes termed. This is especially true if the transformers are small and scattered, as on many lighting systems, although it was commonly done some years ago, when transformers were not made in large sizes and where it was necessary to have a large transformer capacity. Suppose a number of transformers are operating in parallel, as shown in Fig. 24. If they do not all have the same voltage regulation, the load may divide unequally between them and one or more of them take more than its share. The result is that the fuses of the heavily loaded transformer blow, and this throws a heavier load on the remaining transformers. Cases have been known where the fuses would blow one after the other

after they were once started by one transformer taking more than its share of the load. Of course, if the transformers are all of the same size and of similar design, such

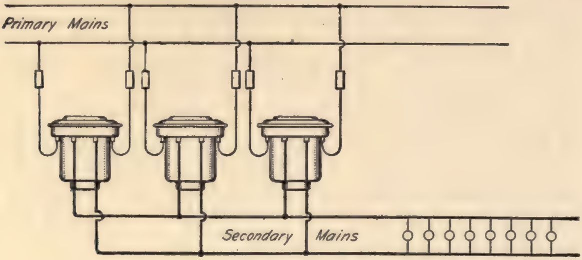


FIG. 24.

trouble is not very likely to happen; but it is better, if possible, to have each transformer supply its own particular part of the load, and if more capacity is needed, to use one large transformer rather than a number of small ones.

76. Transformers are very often wound with their primaries and secondaries in two sections, so that they may be

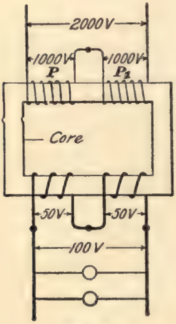


FIG. 25.

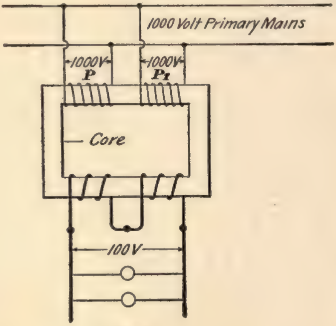


FIG. 26.

connected in series for high voltage and in parallel for low voltage. For example, in Fig. 25 the transformer is wound

with two primary coils P, P_1, each designed for 1,000 volts and two secondary coils each wound for 50 volts. By connecting the coils P, P_1 in series, the transformer may be operated on 2,000-volt mains, and if the secondaries are also connected in series, it will supply current to 100-volt secondary mains. If the two primaries P, P_1 are connected in multiple, as shown in Fig. 26, they may be operated on 1,000-volt mains, and if the secondaries are connected in series, they will supply current at 100 volts. If desired, the secondaries could be connected in parallel to supply current at 50 volts, but the 50-volt secondary circuit is rapidly going out of use. A pressure of 50 volts was, at one time, used quite largely for incandescent lamps operated from transformers, but has given place to 100 to 110 volts, because the latter requires less copper and it is now possible to obtain 100- to 110-volt lamps that operate fully as satisfactory as those made for 50 volts. For operating motors, secondary pressures of 110, 220, or 500 volts are commonly used.

77. In many places, plants that were originally installed to operate at 1,000 volts primary pressure have been changed over to 2,000 volts, in order to allow a larger load to be carried without increasing the size of the line wires. In such cases it has been common practice to connect old 1,000-volt transformers up in pairs, as shown in Fig. 27. In this case, the primaries of the two transformers A, B are connected in series across the 2,000 volt mains and the secondaries are connected in parallel.

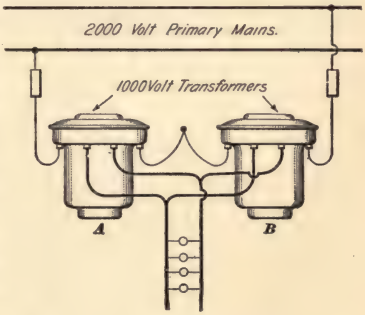


FIG. 27.

78. Transformers on the Three-Wire System.—The general tendency is to use a few large transformers for supplying a given district rather than a number of small ones. Small transformers are wasteful of power, and though each in itself may not represent a very large amount of waste, yet when a large number are connected up, the total amount of energy that might be saved during a year by using a few large transformers may be surprisingly large. Of course, in most cases where the customers are scattered, it is impossible to avoid using a number of small transformers, but in business districts it is generally easy to use

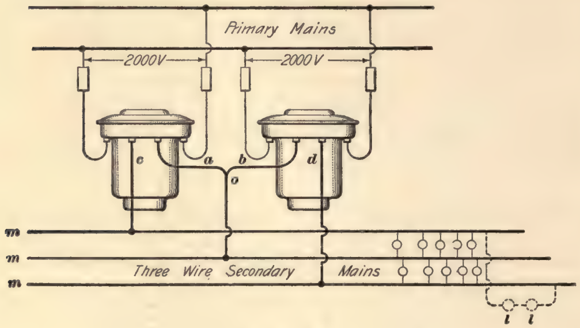


FIG. 28.

a few large transformers of high efficiency. These are frequently connected in pairs so as to feed into three-wire **secondary mains** *m*, *m*, *m*, as shown in Fig. 28. The primaries are connected directly across the line in parallel, and the secondaries are connected in series with the neutral wire connected between them at the point *o*, just as in the case where two dynamos are operated on the three-wire system. Care must be taken in connecting the secondaries to see that the terminals *a* and *b* are of opposite sign. If they are correctly connected, a pair of lamps *l*, *l* connected in series across the outside lines should burn up to full

brightness. If they are wrongly connected, the lamps will not light at all, showing that terminals *a* and *b* are of the same polarity and that *c* and *d* are also the same, the secondaries being connected so that the two outside mains are of the same polarity with a common return wire in the middle. If such is found to be the case, the trouble can be remedied by reversing either one of the primary or secondary connections. It may be well to mention in passing that if two transformers are of the same style and make, the terminals of corresponding polarity will usually be brought out of the case in the same way. For example, in Fig. 22, terminals *a* and *c* would be of the same polarity at the same instant. It is always best, however, to test out the connections before connecting things up permanently, and this is especially necessary in case two transformers of different make or type are being dealt with.

TRANSFORMERS ON TWO-PHASE CIRCUITS.

79. As already mentioned, most two-phase circuits are operated with four wires, and such a system is practically equivalent to two single-phase circuits. The general method of connecting transformers on a four-wire circuit is shown in Fig. 17. If a motor is to be operated, it is necessary to use a transformer on each phase, the capacity of each being one-half that of the motor. When lights are operated, they are connected to each phase in the same way as to a single-phase circuit and the load divided up as evenly as possible between the two phases. If it is necessary to connect two transformers in parallel, as shown at (*a*), Fig. 29, their primaries must both be connected to the same phase. If they were connected to different phases, as indicated by the dotted lines running to Phase *1*, a local current would flow around through the secondary coils, because the two secondary currents would not be in phase and there would be intervals of time when the E. M. F. of one would be greater than that of the other. The secondaries may,

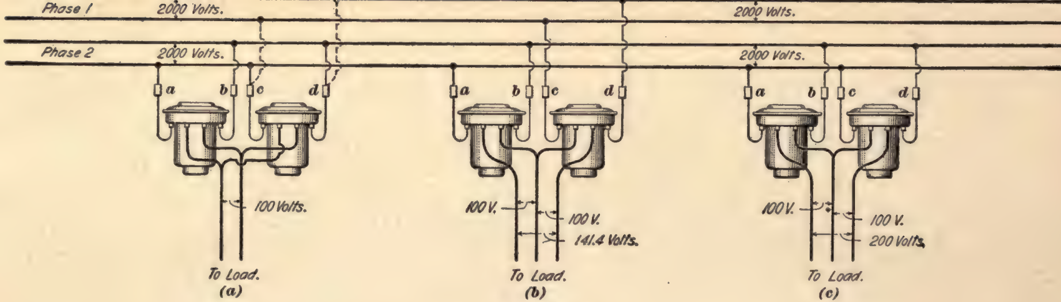

Phase 1
Phase 2
2000 Volts.
2000 Volts.
a
b
c
d
100 Volts.
To Load.
(a)
100 V.
100 V.
141.4 Volts.
To Load.
(b)
100 V.
100 V.
200 Volts.
To Load.
(c)

FIG. 29.

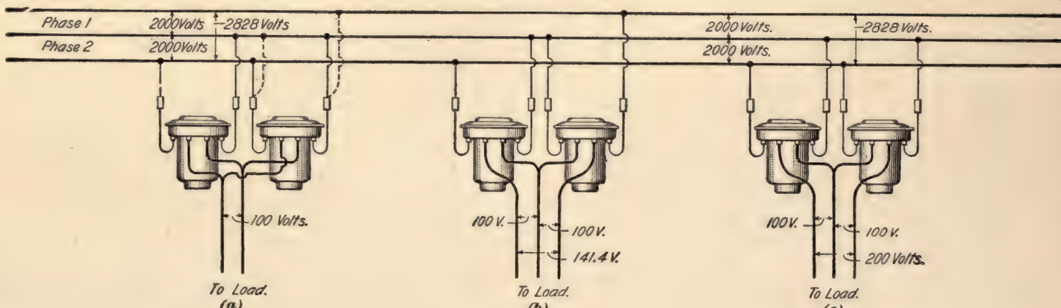
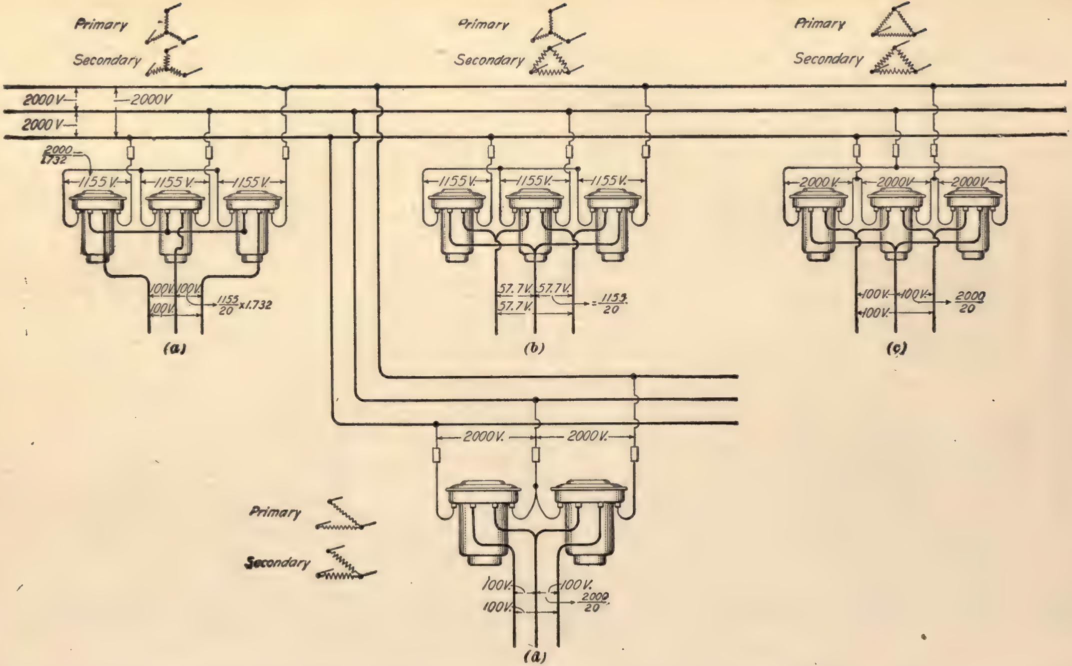

Phase 1
Phase 2
2000 Volts
2000 Volts
2828 Volts
100 Volts.
To Load.
(a)
100 V.
100 V.
141.4 V.
To Load.
(b)
2000 Volts.
2000 Volts.
2828 Volts.
100 V.
100 V.
200 Volts.
To Load.
(c)

FIG. 30.

however, be connected in series as shown at (*b*), when the primaries are connected to different phases, forming a kind of three-wire system. The voltage obtained between the outside wires will not be twice that of one transformer, as in the regular three-wire system. If the voltage of each secondary is E, the voltage between the two outside wires will be $E \times 1.414$. For example, if each secondary gave 100 volts, the pressure between the outside wires would be 141.4 volts. This is because the E. M. F.'s in the two coils are not in phase. This method of connecting up transformers is, however, not to be recommended, as the voltages on the two sides of the three-wire system are apt to become unbalanced. If a three-wire system is desired, it is best to use the connections shown at (*c*), where both primaries are connected to the same phase. The E. M. F.'s in the two secondary coils are in this case in phase with each other and the pressure across the outside wires is twice that of one secondary coil.

80. In connecting transformers to a two-phase system, the aim should be to get the load on the two phases as nearly balanced as possible. Of course, where motors are operated, both phases are used, and, hence, there is not much danger of an unequal division of load. When lamps are connected, one transformer or set of transformers at one point on the circuit can usually be balanced against another group at some other point, so that the load on the whole will be equally divided, as indicated in Fig. 17. Fig. 30 shows a number of different methods of connecting transformers on a two-phase system, using three line wires. In this case, the central wire acts as a common return, and the voltage between the outside wires is 1.414 times that of each phase. The same remarks apply here as in the previous case, and the three-wire arrangement shown at (*b*) is not as generally satisfactory as that shown at (*c*). In both cases the primary pressure is shown as 2,000 volts, and transformers with a ratio of 20 to 1 are taken for the sake of illustration.



Primary
Secondary
2000 V
2000 V
2000 V
2000/1.732
1155 V.
1155 V.
1155 V.
100 V.
100 V.
100 V.
1155/20 x 1.732
(a)
Primary
Secondary
1155 V.
1155 V.
1155 V.
57.7 V.
57.7 V.
57.7 V.
= 1155/20
(b)
Primary
Secondary
2000 V.
2000 V.
2000 V.
100 V.
100 V.
100 V.
2000/20
(c)
2000 V.
2000 V.
Primary
Secondary
100 V.
100 V.
100 V.
2000/20
(d)

FIG. 81.

TRANSFORMERS ON THREE-PHASE CIRCUITS.

81. It is customary in America to use three single-phase transformers for transforming from one pressure to another on three-phase circuits. In Europe, three-phase transformers are used in which there are three primary coils and three secondary coils wound on a three-legged iron core. In America, the general practice is to use three standard single-phase transformers connected up either **Y** or Δ, as the case may be. With the Δ arrangement, the power supply will not be entirely crippled even if one of the transformers should become damaged. In some cases the primaries are connected across the lines according to the **Y** scheme, as shown at (*a*), Fig. 31. By using the **Y** connection, there are two primary coils in series between any pair of mains, and, consequently, the pressure on any one primary coil is less than that between the mains; the pressure on each primary is equal to the pressure between the mains divided by 1.732. When the primaries are connected **Y**, the secondaries are usually connected **Y** also, as shown at (*a*). Sometimes, however, the primaries are connected **Y** and the secondaries Δ, as shown at (*b*). If transformers having a ratio of 20 to 1 were connected in this way, the secondary pressure would not be the primary pressure divided by 20, i. e., 100 volts; but would be $\frac{100}{1.732}$, or 57.7 volts. In order to get 100 volts secondary with this scheme of connections, the transformers would have to be wound with a ratio of $\frac{20}{1.732}$ to 1, i. e., 11.55 to 1, approximately. Fig. 31 (*c*) shows transformers with both primaries and secondaries having Δ connections. The arrangements shown at (*a*) and (*c*) are the ones commonly used in connection with three-phase work, as the other scheme either calls for special windings on the transformers or else gives rise to odd secondary voltages. If the primaries are to be connected Δ, then each primary coil must be wound for the full-line voltage. If the primaries are connected **Y**, each primary coil is wound for the pressure divided by 1.732. It is possible to use only two transformers on a

three-phase system, as shown in Fig. 31 (d), but this arrangement is not on the whole as desirable as the others using three transformers, because if one breaks down the service is crippled. This connection is equivalent to the delta arrangement with one side left out. The connections shown in (c) are doubtless used more largely than any of the others. These connections allow the use of transformers wound for standard voltages and a breakdown of one transformer does not necessarily interrupt the service.

82. Phase-Changing Transformers.—Two-phase currents may be transformed to three-phase, and *vice versa*, by means of an arrangement of transformers devised by Mr. C. F. Scott. Fig. 32 shows the connections necessary. Two transformers A and B have their primary coils P and P' connected to the two-phase mains as shown. The secondary S of transformer A has .87 times as many turns as the secondary S' of transformer B. One end of S is connected to the middle point c of S'. The three-phase lines are attached to terminals e, b, d. This scheme of transformation is used quite largely at Niagara, where two-phase generators are used and the current transformed to three-phase for transmission to Buffalo.

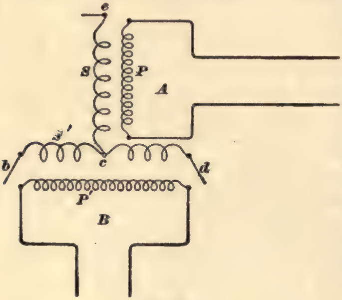


FIG. 32.

83. Capacity of Transformers on Two- and Three-Phase Systems.—When transformers are connected on a two-phase system, as, for example, to feed a two-phase motor, each transformer has to be of capacity sufficient to carry half the load. If the three-phase system using three transformers is used, each transformer must be capable of carrying one-third the load. When the transformers are used to operate induction motors, a safe plan to follow is to

install 1 kilowatt of transformer capacity for every horsepower delivered by the motor. Thus a 20-horsepower, two-phase induction motor would require two 10-kilowatt transformers; a 30-horsepower three-phase motor would require three 10-kilowatt transformers; and so on. The following table, issued by the General Electric Company, shows the size and number of transformers suitable for 60-cycle, three-phase induction motors.

TABLE VIII.

CAPACITY OF TRANSFORMERS FOR THREE-PHASE INDUCTION MOTORS.

H. P. of Motor.	Capacity of Transformers. Kilowatts.	
	Two Transformers.	Three Transformers.
1	0.6	0.6
2	1.5	1.0
3	2.0	1.5
5	3.0	2.0
7½	4.0	3.0
10	5.0	4.0
15	7.5	5.0
20	10.0	7.5
30	15.0	10.0
50	25.0	15.0
75	....	25.0

LINE CALCULATIONS FOR ALTERNATING CURRENT.

84. The factors that determine the size of line wire for a direct-current transmission apply also, in a general way, to alternating-current systems. The resistance of the line causes a drop in pressure between the station and the distant end, and the line must be proportioned so that this

drop will not be excessive. If the load to be carried is practically all lights, and if the distances are not long, the same rules that have already been given for direct-current circuits may be applied with sufficient accuracy to alternating-current lines. If, however, the lines are long, say more than 2 or 3 miles, there are other effects that must be taken into account. It must be remembered that the current is continually changing, and this introduces effects not met with in continuous-current circuits where the current flows steadily in one direction. The size of wire required will depend not only on the amount of the load, but also on the kind of load, i. e., on whether it consists wholly of motors or lights, or a combination of the two. In direct-current circuits, it makes no difference, so far as the drop in the line is concerned, how far the wires are strung apart on the poles, but in an alternating-current circuit this may have an appreciable effect.

85. Self-Induction of Line.—Suppose *A*, *B*, Fig. 33, represent two line wires, and suppose, for the present, that a continuous current is flowing in them. The result of this current will be to set up a magnetic field around each wire as indicated by the dotted circles, and as the current is supposed to be steady, these lines of force will not change in any way and will have no effect on the current. Suppose, however, that the current is alternating instead of continuous. The lines of force surrounding the wires will then change with the change in current; as the current increases, the magnetic field will be built up and lines of force will expand, and as it decreases, the lines will collapse on the wire. The result is that there is a cutting of lines of force by the line wires; or, a still better way of looking at it is that the number of lines threading the space between the wires is constantly changing, and the result of this changing magnetic field is that an electromotive force is set up in the

FIG. 33.

wires. This E. M. F. of self-induction, as it is called, depends on the number of lines of force that are set up between the wires and on the rate at which these lines change; in other words, it depends on the frequency of the current. The effect of this E. M. F. of self-induction is to make the circuit have apparently a greater resistance than it has when direct current is used, because a certain portion of the pressure applied to the circuit is used up in overcoming this E. M. F. of self-induction. By referring to Fig. 33, it will be seen that the farther the line wires are apart, the more room there will be between them for lines to be set up, and, hence, the greater will be the E. M. F. of self-induction. If the wires could be placed side by side in contact with each other, there would be little or no self-induction. This, however, is not possible, and lines, as strung on poles, always possess a certain amount of self-induction. When the two wires are twisted together to form a cable, as in underground work, they have little or no self-induction. The amount of the E. M. F. set up in a conductor depends on the rate at which lines of force are cut. If the alternating current flowing through a line changes very rapidly, it is evident that the E. M. F. of self-induction will be much higher than if it changed slowly, because the cutting of lines of force would not be so great in the latter case.

86. This E. M. F. of self-induction, as stated above, is, to a certain extent, opposed to the current and increases the apparent resistance of the circuit. Its effect is to make the current lag behind the E. M. F., so that the current and E. M. F. do not come to their maximum values at the same instant. This self-induction may also be present to a greater or less degree in the devices that are operated on the circuit. A load of lamps possesses very little self-induction, but a load of induction motors may introduce quite a large amount, and thus make the current lag considerably behind the E. M. F.

87. If we have direct current or if there is no self-induction in the alternating-current circuit, the power

factor is 1, and the watts are given directly by the product of the current and E. M. F. If in an alternating system we have to deliver W watts, the apparent watts, or **volt-amperes,** as they are sometimes called, will be $\frac{W}{f}$, where f is the power factor, and the current will be

$$C = \frac{W}{E \times f}. \qquad \textbf{(13.)}$$

88. The greatest value that the power factor can have is 1, and it has this value very nearly when the load consists wholly of incandescent lamps or any other load that has no appreciable self-induction. Even when the load is all lights, the transformers have a slight amount of self-induction, so that the power factor may be about .98. Where the load is all motors, the power factor may be taken as .80, and where the load is a combination of motors and lights, as about .85.

EXAMPLE.— 10 kilowatts are to be delivered at the end of a transmission line to a load that consists wholly of motors. (*a*) What will be the apparent number of watts delivered, i. e., what will be the product of the current and voltage at the end of the line? (*b*) What will be the current if the pressure at the end of the line is 1,000 volts?

SOLUTION.—Since the load is all motors, we may take the power factor as .80; hence, we have

(*a*) Apparent watts $= \frac{10{,}000}{.80} = 12{,}500$. Ans.

(*b*) The current will be $\frac{12{,}500}{1{,}000} = 12.5$ amperes. Ans.

NOTE.—If the power factor had been 1 instead of .80, the apparent watts would have been the same as the true watts and the current would be 10 amperes.

89. From what has just been said, it will be seen that the effect of an inductive load, and, consequently, low power factor, is to necessitate a larger current for a given amount of power transmitted than would be required if the load were non-inductive. This means, then, that a larger line wire must be provided if the drop is to be kept the same.

FORMULAS FOR LINE CALCULATIONS.

90. Estimation of Cross-Section of Lines.—It has been shown that in a direct-current transmission line a certain drop in voltage is equivalent to a corresponding loss in power. For example, if the drop were 10 per cent. of the delivered voltage, the loss of power in the line would also be 10 per cent. of that delivered at the receiving end. With alternating current, the percentage of drop in pressure may be quite different from the percentage loss in power. In case alternating current were used in the circuit mentioned above, the drop in voltage would very likely be more than 10 per cent., on account of the self-induction of the line. Just what the drop would be, corresponding to a given loss in power, depends on the size of the wire, distance apart on the poles, etc. The exact calculation of line wires for alternating current is a complicated matter, but in nearly all the cases that arise in practice they can be estimated with sufficient accuracy by means of comparatively simple formulas. It is seldom that a wire can be obtained of exactly the same size calculated unless it is made to order, so that the approximate formulas give sufficiently close results for practical work. The following formulas, originated by Mr. E. J. Berg, will be found convenient for estimating alternating-current lines. We will denote the different quantities entering into the calculations as follows:

D = distance in feet over which power is transmitted (this distance is to be taken one way only, i. e., it is the single distance);

W = total watts delivered at the end of the line (this number must express the actual watts delivered, not the apparent watts);

P = percentage of *power* lost in line (it should be noted that this percentage is that of the power *delivered*, not the power *generated;* also, it is the percentage *power* lost, not the *percentage drop in voltage*);

E_2 = voltage required at the receiving end of the line, i. e., the voltage at the end where the power is delivered;

t = a constant having the following values:

2,400 for a single-phase system operating lights only.
3,000 for a single-phase system operating motors and lights.
3,380 for a single-phase system operating motors only.
1,200 for a three-wire three-phase, and four-wire two-phase system, all lights.
1,500 for a three-wire three-phase and four-wire two-phase system, motors and lights.
1,690 for a three-wire three-phase and four-wire two-phase system, all motors.

The cross-section of the wire required for any given case may then be calculated from the following formula:

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t. \qquad \textbf{(14.)}$$

EXAMPLE.— 300 horsepower is to be transmitted by means of the three-phase system over a distance of 5 miles with a loss of 10 per cent. of the power delivered. The pressure at the end of the line is to be 4,000 volts and the power is to be used altogether for operating motors. Calculate the size of line wire required.

SOLUTION.—In this case the distance D is $5{,}280 \times 5 = 26{,}400$ feet. The watts delivered will be $300 \times 746 = 223{,}800$. $P = 10$ and $E_2 = 4{,}000$. The constant t for this case will be 1,690; hence, we have from formula

$$\text{Circular mils} = \frac{26{,}400 \times 223{,}800}{10 \times 4{,}000 \times 4{,}000} \times 1{,}690 = 62{,}407,$$

or about a No. 2 B. & S. Ans.

91. Estimation of Current in Lines.—The current in the line wires of an ordinary continuous-current line is easily obtained by dividing the watts supplied by the voltage at the end of the line. We can obtain the current in the case of alternating-current systems by using a similar formula and multiplying by a constant, to allow for the circumstances under which the current is used. We may then use the following formula:

$$\text{Current in line} = \frac{W}{E_2} \times T, \qquad \textbf{(15.)}$$

where W = watts delivered;
E_2 = voltage at the receiving end of the line;
T = constant referred to above.

VALUES OF CONSTANT T.

Single-phase system, all lights..................	1.052.
Single-phase system, motors and lights.........	1.176.
Single-phase system, all motors................	1.250.
Two-phase, four-wire system, all lights.........	.526.
Two-phase, four-wire system, motors and lights.	.588.
Two-phase, four-wire system, all motors........	.625.
Three-phase system, all lights..................	.607.
Three-phase system, motors and lights.........	.679.
Three-phase system, all motors................	.725.

EXAMPLE 1.— 100 kilowatts are delivered by means of the two-phase, four-wire system to a mixed load of motors and lights. The pressure at the receiving end of the line is 2,000 volts. Calculate the current in each line wire.

SOLUTION.— 100 kilowatts = 100,000 watts. For this case the constant T will be .588; hence,

$$\text{Current} = \tfrac{100000}{2000} \times .588 = 29.4 \text{ amperes. Ans.}$$

EXAMPLE 2.— 200 kilowatts are transmitted by means of the three-phase system, the voltage between lines at the receiving end being 4,000 volts. The load consists wholly of motors; calculate the current in each line.

SOLUTION.— 200 kilowatts = 200,000 watts. For this case the value of T will be .725; hence,

$$\text{Current} = \tfrac{200000}{4000} \times .725 = 36.25 \text{ amperes. Ans.}$$

92. Estimation of Drop.—The volts drop in the line for a continuous-current system would be $\frac{P \times E_2}{100}$, when P is the percentage of delivered power lost and E_2 is the voltage at the receiving end of the line. This formula can be made to give the approximate drop in an alternating-current line by multiplying it by a constant that takes into account the conditions under which the line is operated. We may then write

$$\text{Volts drop in line} = \frac{P \times E_2}{100} \times M. \qquad \textbf{(16.)}$$

The value of the constant M depends on the frequency, the power factor of the load, and the size of the line wire. The value of M, under various conditions, is given in the following table:

TABLE IX.

No. of Wire B. & S. Gauge.	Area. Circular Mils.	Values of M. 30 Cycles. Lights Only.	30 Cycles. Motors and Lights.	30 Cycles. Motors Only.	60 Cycles. Lights Only.	60 Cycles. Motors and Lights.	60 Cycles. Motors Only.	125 Cycles. Lights Only.	125 Cycles. Motors and Lights.	125 Cycles. Motors Only.
0000	211,600	1.26	1.27	1.24	1.64	1.85	1.85	2.44	3.06	3.14
000	167,805	1.20	1.17	1.14	1.49	1.63	1.62	2.15	2.62	2.67
00	133,079	1.15	1.08	1.05	1.39	1.46	1.42	1.92	2.25	2.29
0	105,534	1.10	1.00	1.00	1.30	1.32	1.28	1.73	1.96	1.99
1	83,694	1.06	1.00	1.00	1.23	1.21	1.16	1.57	1.74	1.73
2	66,373	1.03	1.00	1.00	1.16	1.11	1.06	1.44	1.54	1.53
3	52,634	1.02	1.00	1.00	1.11	1.04	1.00	1.35	1.38	1.38
4	41,742	1.00	1.00	1.00	1.07	1.00	1.00	1.26	1.26	1.22
5	33,102	1.00	1.00	1.00	1.04	1.00	1.00	1.19	1.16	1.11
6	26,250	1.00	1.00	1.00	1.02	1.00	1.00	1.14	1.08	1.03
7	20,816	1.00	1.00	1.00	1.00	1.00	1.00	1.09	1.01	1.00
8	16,509	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.00	1.00

Example.— 600 kilowatts are to be transmitted a distance of 6 miles by means of the three-phase 60-cycle system. The loss in the line is to be limited to 10 per cent. of the power delivered, and the pressure at the receiving end of the line is to be 6,000 volts. The current is to be supplied to a mixed load of motors and lights. Calculate (*a*) the size of the line wire; (*b*) the current in each line; (*c*) the volts drop in the line; and (*d*) the pressure generated by the dynamos at full load.

Solution.— 600 kilowatts = 600,000 watts. 6 miles = 6 × 5,280 = 31,680 feet. Using formula **14,** we have, since t for this case is 1,500,

$$\text{Circular mils} = \frac{31{,}680 \times 600{,}000 \times 1{,}500}{10 \times 6{,}000 \times 6{,}000} = 79{,}200.$$

(*a*) A No. 1 B. & S. wire would therefore be used. Ans.

In order to obtain the current in each line we use formula **15,** and for this case the value of T will be .679; hence,

(*b*) $\text{Current} = \frac{600000}{6000} \times .679 = 67.9$ amperes. Ans.

(*c*) In order to calculate the volts drop in the line, we use formula **16.** For a No. 1 wire and a frequency of 60 cycles on a combined

lamp and motor load, the value of the constant M is found to be 1.21 by referring to the table; hence,

$$\text{Volts drop} = \frac{10 \times 6{,}000}{100} \times 1.21 = 726. \quad \text{Ans.}$$

(*d*) Since the drop in the line is 726 volts, the pressure at the dynamo must be $6{,}000 + 726 = 6{,}726$ volts when the full-load current is being delivered. Ans.

NOTE.—In the above example, the drop in the line would have been only 600 volts if continuous current were used.

EXAMPLES FOR PRACTICE.

1. 250 horsepower is to be supplied to 60-cycle induction motors by means of the two-phase, four-wire system over a line 3 miles long. The pressure at the distant end of the line is to be 4,000 volts and the loss in the line is to be limited to 8 per cent. of the power delivered. Calculate (*a*) the size of the wire required; (*b*) the current in each line wire; (*c*) the drop in the line.

Ans. (*a*) 39,000 cir. mils, nearly; about No. 4 B. & S.
(*b*) 29.14 amperes.
(*c*) 320 volts.

2. A three-phase alternator delivers 400 horsepower to a mixed load of motors and lights. The pressure at the distant end of the line is 3,000 volts. Calculate the current in each line. Ans. 67.54 amperes.

3. 5,000 incandescent lamps are supplied with current from a single-phase alternator, having a frequency of 125, over a distance of 3 miles. The loss in the line is to be limited to 10 per cent. of the power delivered and the pressure at the end of the line is to be 3,000 volts. Allow 60 watts for each lamp supplied and calculate (*a*) the size of the line wire; (*b*) the current in the line; (*c*) the volts drop in the line; (*d*) the voltage at the generator.

Ans. (*a*) 126,720 cir. mils, or about No. 00 B. & S.
(*b*) 105.2 amperes.
(*c*) 576 volts.
(*d*) 3,576 volts.

POWER MEASUREMENT.

DIRECT-CURRENT CIRCUITS.

93. It has been shown that the power in watts supplied to any direct-current circuit may be obtained by multiplying the current by the E. M. F. across the lines. For example, in Fig. 34, we may, at any time, obtain the watts supplied to the motor M by multiplying the reading given by the

ammeter *A* by that given by the voltmeter *V*. The number of watts so obtained represents the *rate at which work is being done* at the instant the readings are taken. It must be remembered that the watt is a unit of electrical power, not work, and expresses *rate of doing work*. The electrical unit of work is the joule, and when work is done at the rate of *1 joule per second*, 1 watt is expended. By combining the voltmeter and ammeter we can make an instrument the indications of which will be equal to the product of the current and voltage, and thus indicate the watts directly. Such an instrument is called an *indicating wattmeter*. Fig. 35 shows a Weston wattmeter of the kind referred to. The principle on which this wattmeter operates will be understood by referring to Fig. 36. Two stationary coils, consisting of a few turns of heavy wire, as indicated by *a*, *a*, are mounted side by side, and a small coil *b*, consisting of a large number of turns of fine wire, is mounted between them on jeweled bearings. The motion of the swinging coil is controlled by spiral

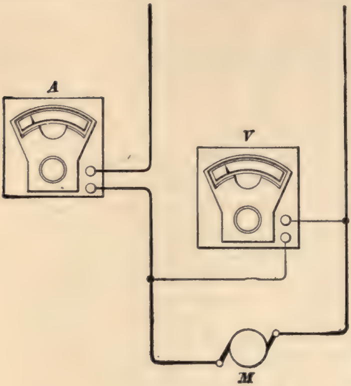


FIG. 34.

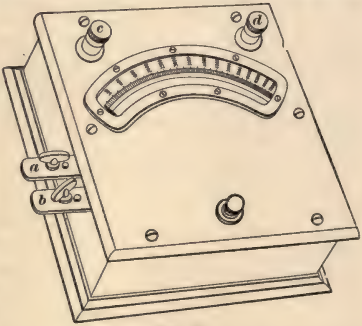


FIG. 35.

springs *c*, *c*, which also serve to carry the current into the coil. The pointer is attached to the axis of the swinging coil and plays over a horizontal scale. The stationary coils *a*, *a* are connected in series in the circuit, so that the current supplied to the motor or other device passes through them. The swinging coil is connected directly across the

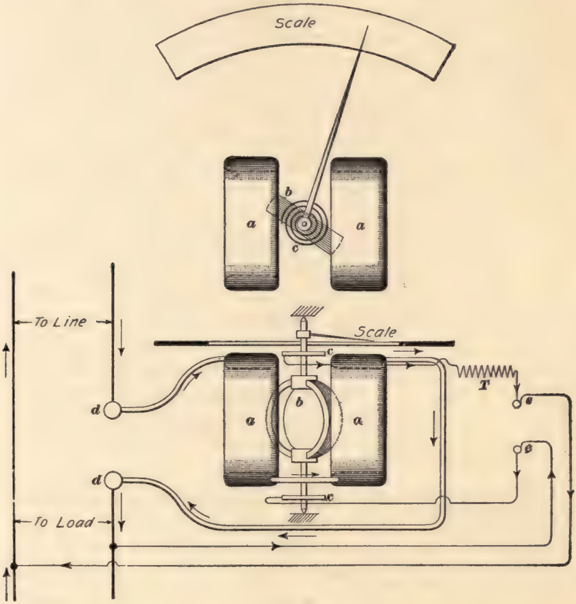


FIG. 36.

circuit, and a high resistance *T* is usually connected in series with the swinging coil, so as to limit the current flowing through it to a very small amount; *d*, *d* are the current terminals of the instrument, i. e., the terminals that connect to the fixed coils; and *e*, *e* are the terminals of the swinging coil.

94. From the way in which the instrument is connected it is seen at once that the current in the fixed coils is the same as the current supplied to the device operated; also, since the swinging coil is connected directly across the circuit, like a voltmeter, the current in the swinging coil will be proportional to the voltage between the lines. Now, the twisting force exerted upon the swinging coil depends on the current in the coil and the strength of the field. The strength of the magnetic field set up through the fixed coil is directly proportional to the current flowing through it, so that the twisting force exerted on the swinging coil depends on the product of the current and the voltage; consequently, the instrument may be graduated to read in watts. Care must be exercised when connecting a wattmeter in a circuit not to get the current and pressure terminals confused, because if the current terminals were connected across the line, a short circuit would result, and the instrument would, in all probability, be destroyed. There is generally no excuse for making such a mistake as this, because the terminals are entirely different in appearance; nevertheless, it has been known to occur. If the fine-wire coil is connected in series in the circuit, no damage will result, but scarcely any current will flow on account of the high resistance so introduced.

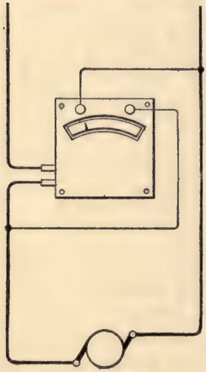


FIG. 37.

95. If an indicating wattmeter were connected to a motor as shown in Fig. 37, it would indicate the power supplied, and its readings would vary as the load on the motor changed. Where power is sold to customers from a central station, it is generally more important to know the total amount of work done during a given interval of time than the power that the motor or other device is taking at any particular instant. For example, the

company supplying power wishes to know just how much work has been done during, say, 1 month, so that the bill may be rendered accordingly. If we do work at the rate of 1 watt, i. e., 1 joule per second, and keep this up for an hour, we do a certain definite amount of work. This quantity of work is known as the **watt-hour.** 1 joule is equivalent to .7373 foot-pound, and .7373 foot-pound per second is 1 watt. If, then, we work at the rate of 1 watt and keep it up for 1 hour, or 60×60 seconds, at the end of the hour we will have done $.7373 \times 60 \times 60 = 2{,}654\ 28$ foot-pounds of work. In order to obtain the total amount of work expended on any device, we must use some instrument that will give us the sum of the products obtained by multiplying each rate of work by its own duration in hours. Such an instrument is known as a **recording wattmeter,** or **watt-hour meter.** The latter name is preferable, because the readings of these instruments do not give watts, but watt-hours.

96. Fig. 38 shows a Thomson recording wattmeter, which is without doubt more largely in use than any other one type. It is in principle a wattmeter similar to that shown in Fig. 36, except that the fine-wire coil is arranged so as to revolve instead of being merely deflected. In order to bring this about, the fine-wire coil is made up in the form of a small drum-wound armature without an iron core, as shown at *a*. This armature is mounted on a vertical shaft and is provided with a small silver commutator, the current being led into the armature by means of the silver-tipped brushes *b*. The current coils are shown at *c*, *c*. The meter is, in fact, a small electric motor without iron in either its armature or field. The lower end of the shaft carries a copper disk that revolves between the poles of permanent magnets. The eddy currents set up in the disk retard the motion of the armature, just as the reaction of the current in the armature of an ordinary dynamo retards the engine. This retarding action of the disk can be adjusted by swinging the poles of the magnets in or out from the periphery.

The speed with which the meter runs is thus made proportional to the watts expended at any given instant, and the *total number of revolutions* that the disk makes in a given period is proportional to the total number of watt-hours of work done during that period.

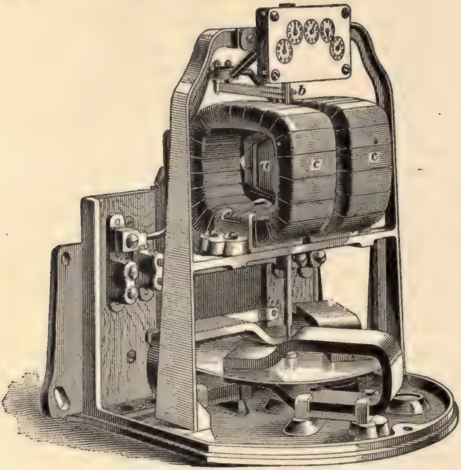


FIG. 38.

The number of watt-hours used during a given time is obtained by taking readings from the dials at the top of the meter in much the same way as a gas meter is read. On some meters, the reading as taken from the dial has to be multiplied by a constant in order to give the watt-hours. This constant is marked on the dial.

97. Fig. 39 shows the method of connecting up a Thomson recording wattmeter of small capacity on a two-wire circuit. The wires from the line always enter the meter at the left, and those going to the load pass out at the right. When the meter is of large capacity, only one side of the circuit is run through it and a small "potential wire" is run

in from the other side, so as to put the armature across the circuit. This method of connection is shown in Fig. 40. Fig. 41 shows a meter connected to a three-wire circuit.

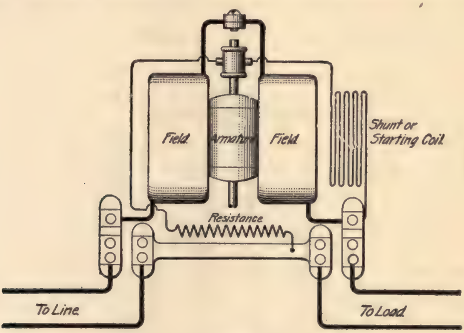


FIG. 39.

The neutral wire does not enter the meter, but a tap is taken off from it so as to put the armature across one side of the

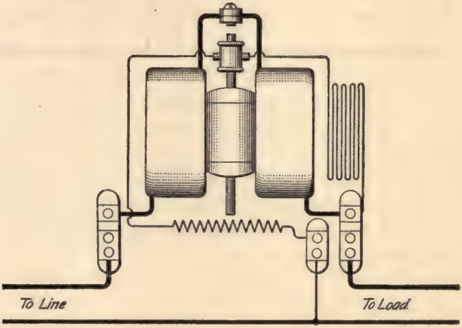


FIG. 40.

circuit. The field coils are connected in series with the outside wires, as shown. In Fig. 39 the starting, or shunt, coil, as it is sometimes called, is a coil of fine wire in series

with the armature and placed inside one of the field coils. It provides just about enough field to start up the meter, so that when a light load is thrown on, the meter will start up readily. The coil is intended to overcome friction and make the meter more accurate on light loads.

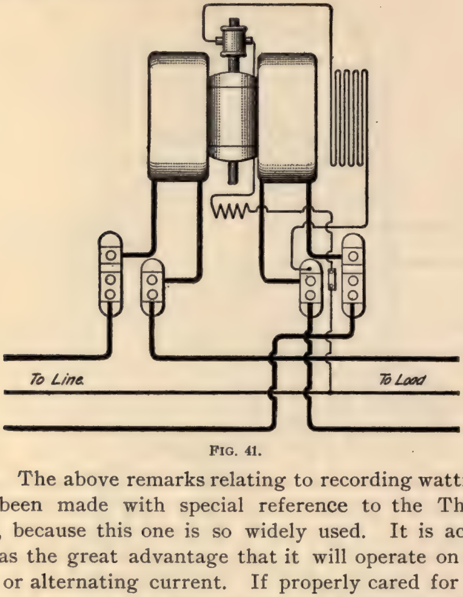


FIG. 41.

98. The above remarks relating to recording wattmeters have been made with special reference to the Thomson meter, because this one is so widely used. It is accurate and has the great advantage that it will operate on either direct or alternating current. If properly cared for it will give good results, but the commutator is delicate and must be kept in good order.

ALTERNATING-CURRENT CIRCUITS.

99. Single-Phase Circuits.—The power supplied to an alternating-current circuit cannot generally be obtained by multiplying the current by the voltage. The power factor of the load must be taken into account, and the only case

where the volts multiplied by amperes would be equal to the watts would be where the device operated had practically no self-induction or electrostatic capacity, as, for example, a load of lamps.

100. The best method of measuring the power supplied to an alternating-current circuit is by means of a wattmeter. There are methods of doing it by means of ammeters and voltmeters, but they are seldom used in practical work. An indicating wattmeter connected as shown in Fig. 37 on a single-phase alternating-current circuit will indicate the actual watts expended. If a record of the watt-hours supplied is desired, a Thomson recording wattmeter may be connected in the same way as for a direct-current circuit, as shown in Fig. 39, 40, or 41, because, as already mentioned, this type of recording wattmeter will work on either direct or alternating current. Also, the Thomson meter may be used on any of the ordinary frequencies and still give accurate results.

101. Induction Wattmeters.—There are a number of different types of recording wattmeters that operate on the principle of the induction motor. In these meters two coils are usually provided (for a single-phase meter), one being a current coil and the other a potential coil. These coils are so arranged that the currents in them differ in phase, and the shifting magnetism so set up acts on a small armature, which usually takes the form of a copper or aluminum disk or drum. Currents are set up in this armature under the influence of the changing magnetic field, just as in the squirrel-cage armature of an induction motor; in fact, induction meters are practically small induction motors. Fig. 42 shows an induction meter (single-phase) made by the Fort Wayne Electric Works. *D* is the revolving aluminum armature, which is in the form of an inverted cup; *a* is the current coil, which is wound on an iron core, the pole piece of which faces *D*. The potential coil occupies a similar position back of the armature *D*, and is therefore not seen in the figure. The fine-wire potential coil is used

in connection with a choke coil, so that the currents in *a* and the potential coil differ in phase, and the result is that a turning effort is exerted on drum *D*. The cup-shaped drum *D* answers both for the armature and damping disk, and the speed control is effected by the permanent magnet *E*, which exerts a dragging action on the armature. The adjustment

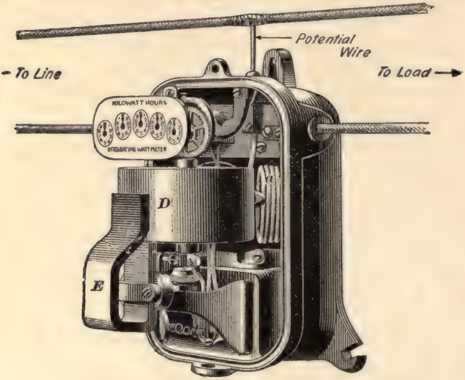


FIG. 42.

of the meter is brought about by raising or lowering *E*, thus making the meter run slower or faster, as desired. Induction meters can, of course, be used on alternating current only and current of the frequency for which they are adjusted. They have one advantage over the Thomson meter in that they have no commutator to give trouble.

102. Ampere-Hour Meters.—Many of the meters formerly used recorded ampere-hours instead of watt-hours. It is evident that the number of ampere-hours gives no idea as to the amount of work done during a given time, unless the pressure at which the current was supplied is known. For example, 200 ampere-hours at a pressure of 50 volts would be equal to 10,000 watt-hours, assuming that the pressure remained constant at 50 volts during the time and that the power factor of the load was 1. If the pressure

were 100 volts, the same meter reading would be equivalent to 20,000 watt-hours. Ampere-hour meters are not used nearly so much as formerly. Practically, all the modern meters are watt-hour meters, and, hence, take account of variations in pressure as well as of current. The earlier types of Westinghouse, or Shallenberger, and Duncan meters measured in ampere-hours. The great objection, however, to the use of ampere-hour meters on alternating-current circuits is that, if the load is at all inductive, i. e., if the power factor is less than 1, they run up a larger bill against the consumer than they should for the actual power supplied. An ampere-hour meter takes no account of the power factor, but simply measures up the current; consequently, for the same actual power used it will run up a larger bill than a recording wattmeter would if it were connected on the same circuit. The customer pays for power, not for current, and the ampere-hour meter readings multiplied by the average voltage would give a larger number of watt-hours than was actually used. Of course, when the load is all lights, the power factor is practically 1, and for such service the ampere-hour meter gives fair readings; but when it comes to measuring power supplied to induction motors or other inductive loads, recording wattmeters should be used.

103. If the power supplied to an alternating-current single-phase circuit is to be measured by means of an ammeter and voltmeter, the power factor f of the circuit must be known. The watts may be obtained by solving formula **13** for W, which gives

$$W = C \times E \times f, \qquad \textbf{(17.)}$$

where C is the ammeter reading and E the voltmeter reading. In most cases, the value of the power factor f is not known exactly, so that it is best to use a wattmeter.

104. Two-Phase Circuits.—In order to measure the power supplied to any receiving device operated on a two-phase system, as, for example, a two-phase induction motor,

it is best to use two wattmeters, one connected in each phase, as shown in Fig. 43. The total power supplied will then be the sum of the readings of the two meters. If the load on the two phases is exactly balanced, one wattmeter may be connected in one phase and its reading multiplied by 2. It is not safe to do this, however, unless it is known that the two sides are balanced. If only one wattmeter is available, it may sometimes be arranged so that it may be

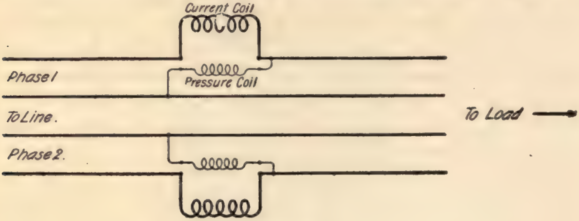


FIG. 43.

connected first in one side and then in the other, but as a rule this is troublesome. On a three-wire two-phase system, the two wattmeters would be connected in very much the same way as shown in Fig. 43, one end of each of the pressure coils being connected to the middle wire. If f is the power factor of a balanced two-phase system, C the current in each phase, and E the E. M. F. per phase; then the watts supplied will be

$$W = 2\,C\,E\,f. \qquad \textbf{(18.)}$$

EXAMPLE.—Power is delivered to a two-phase induction motor having a power factor of .85. The current in each phase is 30 amperes, and the voltage of each phase 220 volts. Calculate the horsepower supplied to the motor.

SOLUTION.—We have

$$\begin{aligned} \text{Watts} &= 2\,C \times E \times f \\ &= 2 \times 30 \times 220 \times .85 \\ &= 11{,}220. \end{aligned}$$

Hence, $\text{H. P.} = \frac{11220}{746} = 15$, nearly. Ans.

105. Three-Phase Circuits.—In the three-phase system we do not usually have three distinct circuits. If three

distinct circuits were used, six wires would be necessary. Each wire serves alternately as the return for the other two, and on this account wattmeters have to be connected somewhat differently than on an ordinary circuit when measurements of power are being made. If the power is supplied to

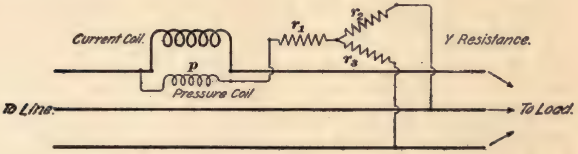


FIG. 44.

a balanced load, as, for example, a load consisting wholly of three-phase motors, one wattmeter may be used to measure the power, as indicated in Fig. 44. The method of connecting the potential coil p and the resistances r_1, r_2, and r_3 should be noted. These resistances are connected as shown in order to obtain an artificial neutral point, similar to the common connection of a Y-connected three-phase armature. This combination of resistances is sometimes called a "Y resistance," or a "Y box." Although the current coil is in one side of the system only, the instrument can be calibrated to read the total watts delivered, assuming, of course, that the load is balanced.

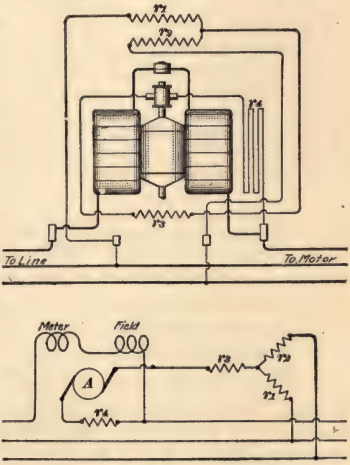


FIG. 45.

106. Fig. 45 shows how to connect a Thomson recording wattmeter with its **Y** resistance so as to measure the power on a balanced three-phase circuit. The recording meters are so calibrated that their reading multiplied by the meter constant, if there is one, gives the total power supplied. Fig. 45 shows the connections when the meter is used on circuits where the pressure is not over 500 volts. When the pressure is higher than this, small transformers t, t, Fig. 46, are used to step down the voltage for the pressure coil of the recording wattmeter, and the connections are as shown in the figure referred to.

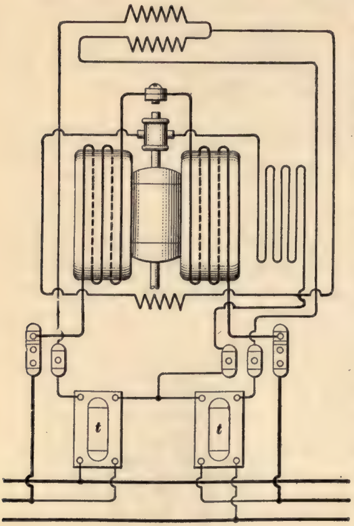


FIG. 46.

107. If the current in each line of a balanced three-phase system is C, the pressure between the lines E, and the power factor of the load f, then the watts delivered will be

$$W = 1.732 \times E \times C \times f. \qquad (19.)$$

EXAMPLE.—A three-phase motor takes a current of 40 amperes from a 500-volt line. How many horsepower are supplied if the power factor of the motor is .80 ?

SOLUTION.—We have

$$\begin{aligned} W &= 1.732 \times E \times C \times f \\ &= 1.732 \times 500 \times 40 \times .80 \\ &= 27{,}712. \end{aligned}$$

Hence, $\text{H. P.} = \frac{27712}{746} = 37.1.$ Ans.

108. The power factor of induction motors varies greatly with the load and also with the size of the motor. The power factor of a good motor of fair size running at full load will usually lie between .85 and .90. When running at $\frac{1}{2}$ to $\frac{3}{4}$ load, the power factor may drop to .75 or .80. For this reason, the student is cautioned against making power calculations in connection with induction motors or any other piece of alternating-current apparatus by multiplying the current and E. M. F. together. Such calculations may be far from correct, unless the power factor is known and taken into account as shown above. Take, for example, the common case where a transformer primary is connected, say, to 2,000-volt mains and its secondary is open and supplying no current whatever. A small current will flow through the primary; in this case we will say .25 ampere. The apparent power that the primary is taking is $.25 \times 2,000 = 500$ watts. If the power were measured by means of a wattmeter, it would be found that the actual power supplied was not nearly as large as this; it might not, in fact, be more than one-half this amount. On the other hand, if the transformer were working on a full load composed of lights, the product of the current and the E. M. F. would give very nearly the actual power, because the power factor would, under such circumstances, be nearly equal to 1.

SPECIAL METERS.

109. The Two-Rate Meter.—Most electric-light stations have their period of heaviest load for a few hours only, in the evening. During the daytime the plant is lightly loaded and a large part of the machinery is standing idle. In order to obtain a "day load" and thus work the plant to best advantage, some companies supply power during the daytime at specially low rates in order to induce customers to use electric motors. For measuring the power supplied to such customers, **two-rate meters** are sometimes used. A two-rate meter is one that records the power during

certain hours of the day separately from the power used in the evening, so that the amount of power to be charged for at the reduced rate may be known. The two-rate meter as brought out by the General Electric Company is a regular Thomson recording meter provided with two dials and recording trains. The meter is also provided with an electrically operated self-winding clock movement that throws either one or the other recording train into gear with the meter at whatever times the clock is set for. For example, the clock might be set so that the meter would record on the low-rate dial from 6 A.M. to 6 P.M. and then be switched over to record on the high-rate dial from 6 P.M. to 6 A.M. The changing over from one dial to the other is accomplished by means of two small friction clutches controlled by the clock.

110. The Maximum-Demand Meter.—The maximum amount of current that the various customers consume, to a large extent determines the capacity of the equipment that must be provided for the station. Some customers might use large currents for short intervals, but the plant would have to be capable of delivering these large currents, and in some cases, therefore, the maximum demand for current is taken into account in charging for the supply of current. One style of instrument used for indicating the maximum current used by a customer is the Wright demand meter. In this instrument the main current passes around a flat conductor that encircles a bulb on the top of one branch of a U-shaped tube, which is partly filled with liquid. When current flows through the strip the bulb becomes heated, thus expanding the air and forcing liquid into a bulb on the top of the other branch of the U tube, from which it flows into a vertical tube closed at the lower end. The amount of liquid thus forced into this tube, by the expansion due to the heating effect of the main current, is a measure of the maximum current used by the customer, and this reading, in conjunction with the reading of a regular watt-hour meter, can be used in determining the charge to be made.

INSTALLATION AND OPERATION OF RECORDING METERS.

111. When an electric light or power company supplies power to a consumer, they wish to know the total amount of energy supplied during a given time, say 1 month, rather than the amount of power that the customer is using at any particular time, just as a gas company wishes to know the total number of cubic feet of gas used during the month rather than the number of cubic feet used by the customer at different times during the month. In order to get at this, recording wattmeters or ampere-hour meters are installed. The former read in watt-hours and the latter in ampere-hours. A recording wattmeter records watt-hours and not watts, giving the product of the average number of watts used by the time during which it was used. For example, one day the customer's motors or lights might take 3,000 watts for 10 hours (30,000 watt-hours), and the next day only 1,000 watts for 3 hours (3,000 watt-hours), and so on. The recording wattmeter, or, more properly, the watt-hour meter, averages up all these values, and by taking the reading at the end of the month and subtracting the previous reading, the watt-hours of electrical energy used during the month may be obtained. One kilowatt-hour is equal to 1,000 watt-hours, and since 1 horsepower is equal to 746 watts, 1 kilowatt-hour equals $\frac{1000}{746}$ horsepower-hours. One kilowatt-hour is, therefore, equivalent to about $1\frac{1}{3}$ horsepower expended for 1 hour.

112. As stated above, some meters, especially those of the older types, record ampere-hours. It is evident that ampere-hours are not a true measure of the work done, because no account is taken of the voltage. If the voltage can be assumed to be constant, a fairly close estimate of the watt-hours may be obtained by multiplying the ampere-hours by the voltage. In what follows, we will confine our attention to the Thomson recording wattmeter, as this is used more extensively than any other one type.

113. Installation of Meters.—Directions are sent out with each particular type of meter, giving points to be observed in setting up and connecting. See that the meter is leveled properly, that the shaft turns freely, and that the commutator and brushes are in good condition. Be sure that it is placed in a position where it will not be subjected to vibration, as this is very liable to injure the jewel and pivot. Mount the meter on a brick wall, if possible, and do not place it near where a door is being continually opened and shut. Also place it where it will not be exposed to dampness, an unusual amount of dust, or chemical fumes of any kind.

114. Testing Meters.—Recording wattmeters should be checked up with a standard direct-reading meter occasionally to see if they record correctly. In order to do this, the meter is set to work on a load of lamps, or other convenient resistance, the standard direct-reading wattmeter being connected as shown in either Fig. 47 or Fig. 48. A

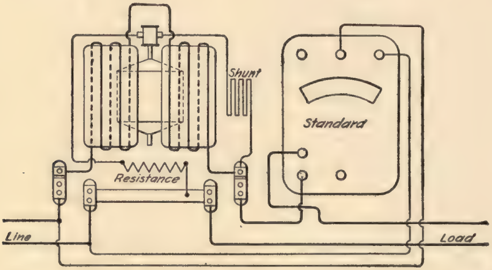


FIG. 47.

chalk mark is made on the meter disk, so that the revolutions may be easily counted, and the revolutions are taken for 40 to 60 seconds, the observer using a stop watch. Another observer reads the standard instrument, and the load is kept as nearly constant as possible throughout the test. The meter watts may then be calculated from the following formula:

$$\text{Meter watts} = \frac{R \times K \times 3{,}600}{T}, \qquad \textbf{(20.)}$$

where

R = number of revolutions in T seconds;
T = time in seconds of R revolutions;
K = constant of meter (this is marked on the meter dial).

The actual watts are obtained from the standard meter, hence the percentage by which the meter is correct is found by dividing the watts as given by formula **20** by the watts as given by the standard meter.

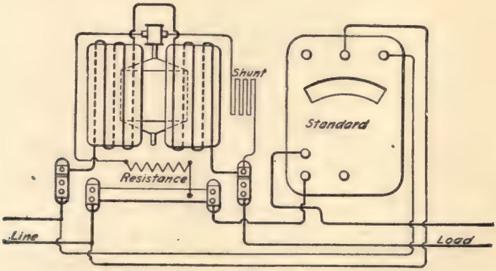


FIG. 48.

EXAMPLE.—The disk of a 10-ampere, 100-volt Thomson meter makes 10 revolutions in 60 seconds. The average standard watts as indicated by the standard meter are 303. Find the percentage error of the recording meter. The constant of the meter is $\frac{1}{2}$.

SOLUTION.—From formula **20,** we have

$$\text{Meter watts} = \frac{10 \times \frac{1}{2} \times 3{,}600}{60} = 300.$$

$$\tfrac{300}{303} = .99, \text{ or } 99\%. \quad \text{Ans.}$$

The meter is, therefore, 1 per cent. too slow, and the damping magnets should be shifted in a little so that the retarding action on the disks will not be so great.

115. If a standard wattmeter is not available for testing purposes, separate ammeters and voltmeters may be used for direct-current work, but they are not as convenient

In Figs. 47 and 48, it will be noticed that the energy consumed in the potential circuit of either meter is not measured by the other; that is, the current in the armature of the Thomson meter does not pass through the fields of the standard meter; neither does the current in the shunt of the standard pass through the field coils of the Thomson meter.

116. To test a meter used on a three-wire 110- to 220-volt circuit it may be connected as shown in Fig. 49. The potential circuits of these meters are wound for 110 volts. The field coils can, therefore, be connected in series, and

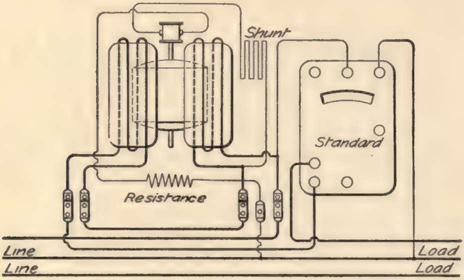


FIG. 49.

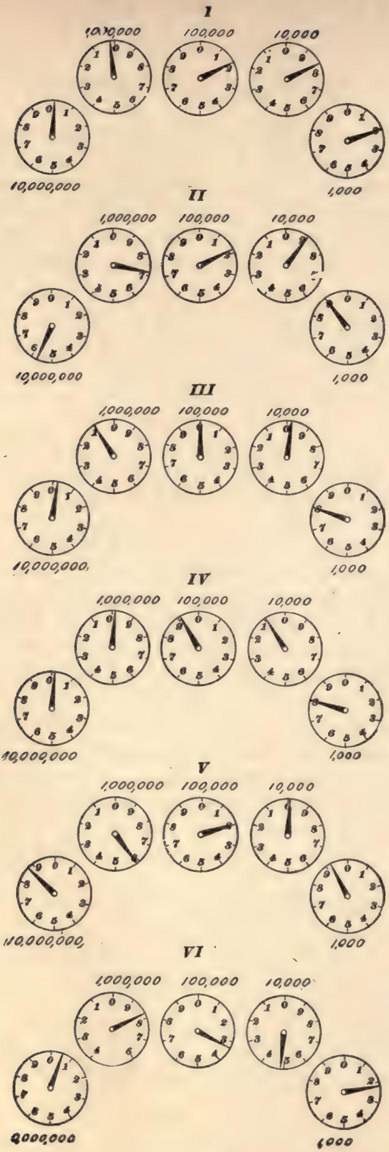
the standard meter connected in as shown in Fig. 49. In formula **20**, however, K should only be taken as one-half the constant marked on the dial. Aside from this, the meter can be tested in the same manner as a two-wire meter.

117. Cleaning Meters.—The first thing to be done in cleaning meters is to blow out the dust. A small syringe is useful for this purpose. Parts that can be reached should be wiped out with a cotton cloth. Clean the top bearing and worm-gear, but do not oil them, as the oil is liable to find its way on to the commutator. If the train of the counter is stiff, give it a bath in gasoline. Next see that the brushes present a clean, flat, smooth surface to the

commutator. A piece of crocus cloth glued to a narrow, thin stick answers for polishing the brushes, except in cases where grooves are worn in them. If this is the case, a small fine-grained file may be used before polishing. After the brushes are put in proper shape, the commutator should be polished with a narrow strip of cotton tape, or, if necessary, a worn strip of crocus cloth. To use the crocus cloth or tape, pass it around the commutator, cross the ends in front to prevent catching the brushes, then pull the strip back and forth, at the same time twirling the rotating part. The spaces between the commutator segments can be cleaned out with a stick whittled to a thin, flat point.

118. The jewel and pivot on the lower end of the shaft should next be carefully examined. The jewel can be tested with a fine-pointed needle, and if found rough or scratched, it should be replaced by a new one. The shaft end or pivot may be removed with a special tool provided for the purpose, screwed into the end of an old shaft, and any roughness detected by rubbing it over the finger nail. If found rough, a new shaft end should be put in. A drop of good clock oil may be put on the jewel, except when the meter is in a dusty place. Sometimes a wire in the armature of a meter becomes broken, in which case the meter will not come up to speed even with the magnets swung in as far as they will go. Again, if the meter cannot be brought down to the proper speed, the magnets may be too weak or there may be a short circuit in the resistance in the back of the meter, thus letting too much current through the armature.

119. Reading Meters.—Reading meters is considered a difficult task by many, but once the dials are thoroughly understood there should be no trouble in reading correctly. The dials on a recording wattmeter bear a considerable resemblance to those on a gas meter. The arrangement differs somewhat with different makes, but if one is able to read the Thomson meter correctly, there should be little difficulty with the others.


I
1,000,000
100,000
10,000
10,000,000
1,000
II
1,000,000
100,000
10,000
10,000,000
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III
1,000,000
100,000
10,000
10,000,000
1,000
IV
1,000,000
100,000
10,000
10,000,000
1,000
V
1,000,000
100,000
10,000
10,000,000
1,000
VI
1,000,000
100,000
10,000
1,000

FIG. 50.

120. The Thomson meter has five dials. The lowest reading pointer is the one to the extreme right (facing the meter); it is marked 1,000, and this means that *one complete revolution* of the hand indicates 1,000 watt-hours, and each division, therefore, represents 100 watt-hours. The next one to the left is 10,000 to a revolution, or 1,000 for a division, and so on. Fig. 50 shows six different readings, and by studying these, the student should be able to take readings from any meter. Some of these figures have the hands in positions that are liable to puzzle the beginner.

Beginning at the left, number the pointers 1, 2, 3, 4, and 5. Then, in *I*, Fig. 50, pointer 5 is on *2* and is read "200." Pointer 4 is two-tenths of the way between *8* and *9* and is read "8,000." Pointer 3 is read "10,000." Pointer 2 has not gone through its first division; likewise pointer 1. The statement of the meter is then 18,200, and is to be multiplied by the constant of the meter to reduce to watt-hours.

The statement of *II* is 5,718,900 (not 5,719,900, as it frequently would be read). Pointer 4 should not be read "*9*" until pointer 5 has completed its revolution and is again at *0*.

The statement of *III* is 99,800 (not 109,800), because the 100,000 mark will not be reached until pointer 5 has passed from *8* to *0*, when 4 and 3 will be at *0*, pointer 2 at *1*, and pointer 1 just past the zero mark.

The statement of *IV* is 9,990,800. Pointer 1 is slightly misplaced. Otherwise, the reasons given above will apply to this statement.

The statement of *V* is 8,619,900. Pointer 2 is misplaced; for it should be two-tenths of the way between *6* and *7* instead of nearly over *6*, as shown.

The statement of *VI* is 834,200. Pointer 4 is misplaced; it should be two-tenths of a division to the right of 4, instead of as shown. These misplaced hands are frequently met with in practice and are generally caused by a knock in removing the cover, or, perhaps, they are a little eccentric.

121. Rule.—*To ascertain the number of watt-hours that have been used by a consumer from one date to another, subtract the earlier statement from the latter and multiply by the constant of the meter.*

Sometimes no constant is marked on the meter, in which case the reading as taken from the dial is watt-hours, or, in other words, the constant is 1.

EXAMPLE.—Suppose the statements as given by Fig. 50 were taken at the following dates:

Statement January 30 $(V) = 8{,}619{,}900$.
Statement February 28 $(IV) = 9{,}990{,}800$.
Statement March 31 $(I) = 18{,}200$.

The constant of the meter is supposed to be $\frac{1}{2}$.

SOLUTION.—The watt-hours supplied between January 30 and February 28 $= (9{,}990{,}800 - 8{,}619{,}900) \times \frac{1}{2} = 685{,}450$. Some prefer to first multiply each reading by the constant and then subtract as follows: $\frac{1}{2} \times 9{,}990{,}800 - \frac{1}{2} \times 8{,}619{,}900 = 685{,}450$.

The watt-hours supplied between February 28 and March 31 are obtained as follows: It will be noticed that 10,000,000 is the highest reading of the meter and that between the two above dates the meter has run up to its highest point and has registered 18,200 anew. The watt-hours will therefore be

$$(10{,}000{,}000 - 9{,}990{,}800) \times \tfrac{1}{2} + 18{,}200 \times \tfrac{1}{2} = 13{,}700. \quad \text{Ans.}$$

ELECTRIC TRANSMISSION.

(PART 2.)

LINE CONSTRUCTION.

1. Line construction may be considered conveniently under two heads: (*a*) *overhead construction*; (*b*) *underground construction.*

For nearly all work in towns and small cities or for cross-country work, the lines are supported on poles. In cities, the current is now usually distributed, at least so far as the central part of the cities is concerned, by means of wires or cables run in underground tubes or ducts. This method is, of course, much more expensive than the overhead method; but the large increase in the number of wires used for different electrical purposes has rendered underground distribution in cities almost absolutely necessary.

OVERHEAD CONSTRUCTION.

POLES.

2. Selection of Poles.—The poles used to the greatest extent in this country are of the following kinds of wood: white cedar, Norway pine, chestnut, and cypress. The average lives of these, under average conditions, are placed by good authority at the following values:

Norway pine........................	6 years.
Chestnut	15 years.
Cypress........................	12 years.
White cedar	10 years.

Cedar poles are undoubtedly used to the greatest extent. Considering their strength, they are light in weight, and, by some authorities, are considered the most durable, when set in the ground, of any American wood suitable for pole purposes.

3. Sizes of Poles.—The best lines in this country use no poles having tops less than 22 inches in circumference. If the poles taper at the usual rate, the specification that a pole shall have a top 22 inches in circumference, or approximately 7 inches in diameter, is usually sufficient, for the diameter at the butt will then be approximately correct, no matter what may be the length of the pole.

4. Where a pole line is to carry but few wires, it is unnecessary to make the poles so heavy, and in many cases poles with a 5-inch top will answer every purpose. In determining the height of poles, several considerations must be borne in mind. The number of wires to be carried, and therefore the number of cross-arms, determines to some extent the general height of the pole to be used.

5. Spacing of Poles.—Practice varies as to the spacing of poles. Of course, the number and sizes of the wires to be carried is the most important consideration in determining this point, but the climatic conditions, especially with regard to heavy wind and sleet storms, should also be considered. In general, it may be said that the best lines carrying a moderate number of wires use 40 poles to the mile, while for exceptionally heavy lines, the use of 52 poles to the mile, or one pole every hundred feet, is not uncommon practice. As a general rule, which it is safe to follow in the majority of cases 35 or 40 poles to the mile should be used. For city work, the poles should be set on an average not farther apart than 125 feet.

CROSS-ARMS.

6. The cross-arms should be made of well-seasoned, straight-grained, Norway pine, yellow pine, or creosoted

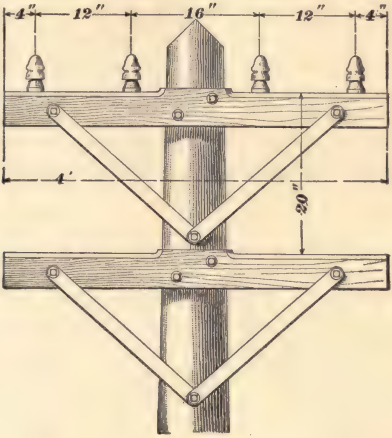


FIG. 1.

white pine. Cross-arms are made in standard sizes, the length of the arm depending on the number of pins it is intended to hold. The standard cross-arm is $3\frac{1}{4} \times 4\frac{1}{4}$ inches, and varies in length usually from 3 to 8 feet. They are usually bored for $1\frac{1}{2}$-inch pins and provided with holes for two $\frac{1}{2}$-inch bolts. The arms are generally braced by flat, iron braces, about $1\frac{1}{4}$ inches wide by $\frac{1}{4}$ to $\frac{3}{8}$ inch thick. These braces are shown in Fig. 1, which gives a view of an ordinary pole top provided with two 4-pin cross-arms.

PINS.

7. The pins by which insulators are mounted upon cross-arms are shown in Fig. 2. They may be made of locust, chestnut, or oak (the woods being

FIG. 2

preferred in the order named), and are turned with a coarse thread on the end on which the insulator is to be secured. The shank K is turned $1\frac{1}{2}$ inches in diameter.

The pin should be secured in the hole by driving a nail through the arm and the shank of the pin. This renders it difficult to extract the shank of the pin in case a new one is required; but, on the other hand, it prevents the pin pulling out, which sometimes occurs when this precaution is not taken. For heavy lines, pins are used that have an iron bolt passing through them. Fig. 3 shows a pin for this kind designed by F. Locke, with a heavy insulator for carrying a cable in the groove *a*.

INSULATORS.

8. Insulators in this country are usually made of glass, while in Europe porcelain is more commonly used. Porcelain, when new, is a better insulator than glass; but it is more costly, and under the action of cold the glazed surface becomes cracked. When this happens, the moisture soaks into the interior structure, and its insulating quality is greatly impaired. Tests recently made have shown that when newly put up, the insulation resistance of porcelain insulators is from 4 to 8 times better than glass, but that along railroads and in cities smoke forms a thin film upon each material, so that at the end of a few months their insulating properties are nearly alike. On country roads, away from railroad tracks, the porcelain insulators maintain a higher insulation than the glass during rain storms, but in fine weather it is not so high. Porcelain has an

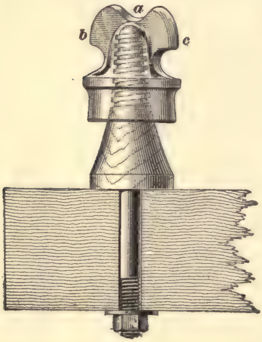


FIG. 3.

advantage over glass in that it is not so brittle, and, therefore, less likely to break when subjected to mechanical shocks. Porcelain does not condense and retain on its surface a thin film of moisture so readily as glass, i. e., it is less hygroscopic. On the other hand, however, glass insulators are not subject to such an extent as porcelain to the formation of cocoons and cobwebs under them, the transparency of the glass serving to allow sufficient light to pass through the insulator to render it an undesirable abode for spiders and worms. As cocoons, cobwebs, etc. serve to lower the insulation of the line to a great extent, this is an advantage that, in this country, it is not well to overlook.

9. Types of Insulators. — For ordinary work with moderate pressures, glass insulators are used. The style of insulator will depend to some extent on the size of wire to be supported. Most power-transmission lines are of weather-proof wire or cable; wires smaller than No. 6 or 8 B. & S. are seldom put up, hence the glass insulators, as a

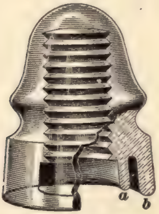


FIG. 4.

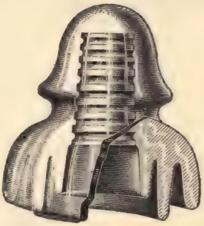


FIG. 5.

rule, must be heavier than the kind used for telegraph or telephone work. Fig. 4 shows an insulator, known as the D. G. (deep groove), that is well adapted for ordinary lines. This insulator is so called to distinguish it from those with smaller grooves, such as are used for telephone or telegraph work. It is provided with two petticoats, or flanges, *a*, *b* over which leakage must take place before the current can

leak from the wire to the pin. The use of a number of petticoats increases the leakage distance and provides a high insulation. Insulators used on high-tension lines are provided with a number of such petticoats. When heavy cables are used, it is customary to carry them on especially heavy insulators and to tie down the cable on top of the insulator instead of tying it to the side. Fig. 3 shows a common type of such insulator. The cable rests in the groove *a* and is held in place by a tie-wire twisted around the cable and passing under the ears at *b*, *c*. Good quality glass insulators, such as those just described, may be used for any lines where the potential is not over 2,000 or 3,000 volts. For higher pressures on transmission lines, it is better to use a larger insulator giving a higher degree of insulation.

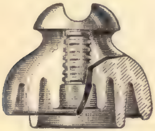


FIG. 6.

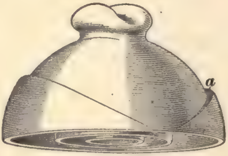


FIG. 7.

Fig. 5 shows a Locke insulator of glass that is suitable for any pressure up to 5,000 volts. This insulator is 4½ inches in diameter, and it will be noted is provided with three petticoats, thus giving a long leakage distance from the wire to the pin. Fig. 6 shows a still larger insulator; this one is suitable for pressures up to 25,000 volts and is 5½ inches in diameter. For high pressures, porcelain insulators have been largely used; as yet there does not seem to be any settled opinion as to just which is the better, glass or porcelain, for this kind of work. Fig. 7 shows a type of porcelain insulator that is used extensively in connection with the Niagara transmission plant. These insulators are elliptical, or "helmet," shaped and have an eave, or ridge, *a* on each side. The object of these ridges is to run off the water to the end of the insulator, where it will drop clear of

the cross-arm. These extra large insulators are only necessary for the high-tension lines, and by far the greater part of electric-light lines are carried on ordinary glass insulators of the type shown in Figs. 3 or 4.

TYING AND SPLICING.

10. Tying.—Fig. 8 shows the method of tying that is commonly used. The tie-wire *a* is usually from 12 to 16 inches in length and should be insulated to the same extent as the wire to be tied. The line wire is laid in the groove of the insulator, after which the two ends of the tie-wire, which have been passed half way around the insulator, are wrapped tightly around the wire. Some linemen advocate the plan of starting to wrap one end of the tie-wire over and the other end under the line wire. Fig. 9 shows a method of tying that is used where the wire lies on top of the insulator.

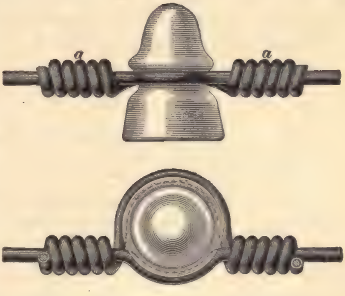


FIG. 8.

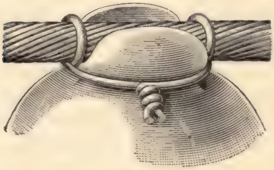


FIG. 9.

11. Splicing.—The American wire joint shown in Fig. 10 is generally used where splices must be made. The wires are placed side by side and each end wound around the other. All joints should be soldered. The rules of the National Board of Fire Underwriters require that all line joints shall be mechanically and electrically perfect before being soldered; i. e., solder should not be depended on to

make the joints strong mechanically or efficient as an electrical conductor. In other words, soldering should always be done simply as a safeguard against any diminution in

FIG. 10.

the electrical conductivity of the joint. Large cables are joined either by weaving the strands together and soldering or by using a copper sleeve into which the ends of the cable are fastened.

UNDERGROUND CONSTRUCTION.

12. In cities, it is necessary to place the wires underground, especially in the business districts. The best way to do this is to provide a regular tunnel, or **subway,** in which the various wires, or cables, can be placed and which will be large enough to allow a man to walk through for inspection or repair. This method is, however, very expensive and can only be used in a few very large cities. Another method is to use **conduits** through which to run the cables. These conduits usually consist of tubes of some kind that are buried in the ground and thus provide ducts into which the cables may be drawn. These ducts terminate in **manholes,** usually placed at street intersections, by which access may be had to the cables and from which they may be drawn into or out of the ducts. A third method, and one that has been largely used in cities for distributing current for lighting purposes, is to bury tubes containing insulated conductors in the ground. In this system the conductors cannot be withdrawn, as in the conduit system, and there is a separate tube for each set of conductors. The Edison tube system belongs to this variety, and a very large amount of lighting on the three-wire system has been carried out by using underground conductors of this kind.

CONDUITS.

13. A large variety of **conduits** are in use, and it has not been definitely settled as yet just which type is the best; but the following will serve to give an idea as to some of the more common forms that have stood the test of actual work and are in extended use.

14. Creosoted-Wood Conduit.—A form of conduit largely used, and which has the advantage of being very cheap to install, is one that is composed of sections of wooden tubing, the fiber of the wood being impregnated with creosote, in order to prevent its decay. This form of conduit is commonly known as **pump-log conduit,** on account of the resemblance of the wooden sections to the ordinary form of wooden pump logs. A section of this conduit is shown in Fig. 11; the ends are doweled in order to preserve the proper alinement in joining. These sections are usually 8 feet in length, and have circular holes through their centers from $1\frac{1}{2}$ to 3 inches in diameter, according to the size of cable to be drawn in. The external cross-section is square and $4\frac{1}{2}$ inches on the side, in the case of a tube having a 3-inch internal diameter. Such a conduit as this, if properly impregnated with creosote, will probably have a life of from 15 to 20 years, and perhaps much longer, this point being one concerning which there is considerable argument and which, probably, time alone will decide. In some cases, difficulty has been experienced with creosoted-wood conduits on account of the creosote attacking the lead covering of the cables.

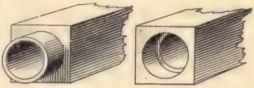


FIG. 11.

15. Cement-Lined Pipe Conduit.—This conduit, made by the National Conduit and Cable Company, is now largely used for underground wires. The sections shown in Fig. 12 are usually 8 feet long and are made as follows: A tube is made of thin wrought iron, No. 26 B. W. G., .018 inch thick

and securely held by rivets 2 inches apart. The tube is then lined with a wall of Rosendale cement $\frac{5}{8}$ inch thick, the inner surface of which is polished while drying, so as to form a perfectly smooth tube. This tubing comes in three sizes, each having a length of 8 feet and internal diameters of

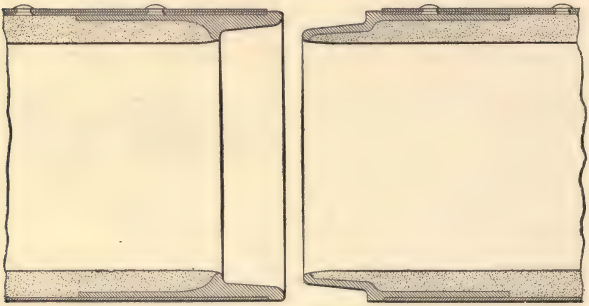


FIG. 12.

2, $2\frac{1}{2}$, and 3 inches, the latter being the standard size. Each end is provided with a cast-iron, beveled socket joint, by the use of which perfect alinement may be obtained by merely butting the ends together. These beveled socket joints also allow of slight bends being made in the line of conduit as it is being laid.

16. Vitrified-Clay or Terra-Cotta Conduit.—A form of conduit that is probably used in good construction work to a greater extent than any other is made of vitrified clay. This material has the advantage of being absolutely proof against all chemical action, and unless destroyed by mechanical means will last for ages. Besides this, its insulating properties are high and it is comparatively cheap and easily laid.

When clay conduits were first used, it was customary to form various sections with two or more ducts, one of the

most common form being the 4-duct type, two sections of which are shown in cross-section in Fig. 13. These are made with 2, 3, 4, 6, and 9 ducts, all in 8-foot lengths. In another form, each section had 2 ducts only, these ducts being large enough to accommodate several cables. In this form, however, much trouble has been experienced, due to the fact that when several cables are laid in a single duct, it often becomes impossible to withdraw them, owing to the fact that they are much more likely to become wedged than in the forms where one cable only occupies a single duct. It is not good practice to put more than one cable in the same duct.

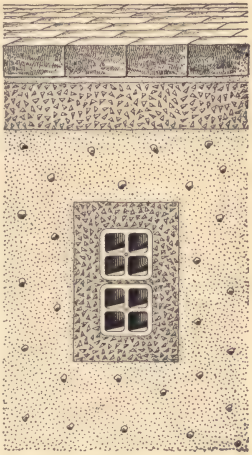


FIG. 13.

17. The form of clay conduits now most commonly used is shown in Fig. 14, this being usually made in 18-inch lengths, having an internal diameter of from 3 to $3\frac{1}{4}$ inches and being $4\frac{5}{8}$ inches square outside. This duct has a great advantage over the multiple-duct sections in the greater ease of handling and also in the fact that it is much less liable to become warped or crooked in the process of burning during its manufacture than the larger and more complicated forms. Like the cement-lined pipe, it is laid on a bed of concrete, cemented

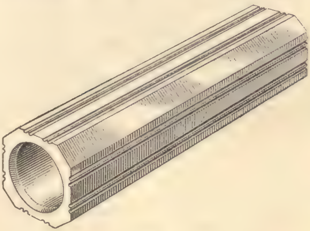


FIG. 14.

together with mortar, and enclosed on all sides and on top by concrete. In laying, a wooden mandrel, such as is shown in Fig. 15, 3 inches in diameter and about 30 inches in length, is used. At one end is provided an eye *a*, which may be engaged by a hook, in order to draw it through the

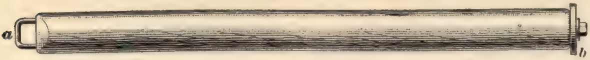


FIG. 15.

conduit, while at the other end is secured a rubber gasket *b* having a diameter slightly larger than that of the interior of the duct. One of these mandrels is placed in each duct when the work of laying is begun. As the work progresses,

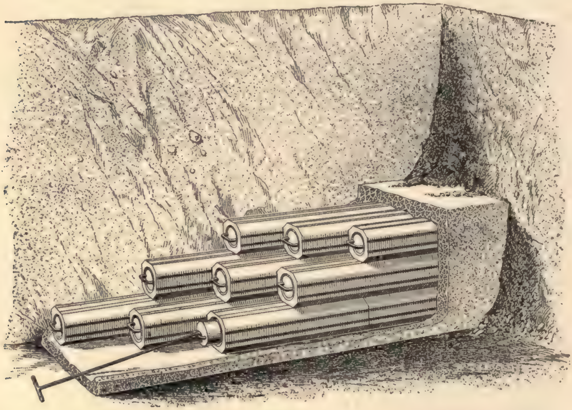


FIG. 16.

the mandrel is drawn along through the duct by the workmen, by means of an iron hook at the end of a rod about 3 feet long, the method of doing this being shown in Fig. 16. By this means, the formation of shoulders on the inner walls of the ducts at the joints is prevented, and any dirt that may have dropped into the duct is also removed. The

cylindrical part of the mandrel insures good alinement of the ducts, thus securing a perfect tube from manhole to manhole.

18. Fig. 16 illustrates the method of laying this conduit, and shows how the joints should be broken in the various layers so as to insure a maximum lateral strength to the structure.

All conduits should be laid to such grades that there will be no low points or traps in the conduit that will not drain into the manholes.

MANHOLES.

19. Manholes form a very important part in cable systems and require careful designing to properly adapt them to the particular conditions to be met. They are usually placed about 400 feet apart, and if possible, at the intersection of streets. They should be located with a view to making the line of conduit between them as nearly straight as possible. The size of the manhole will depend on the number of ducts that are to be led to it, as well as the number of men that will be required to work in it at one time. Manholes 6 feet square and from 5 to 6 feet high will usually be required for large systems, while for smaller systems, or the outlying portions of large ones, they may be made as small as 4 feet in length, in the direction of the conduit, 3 feet wide and 3 or 4 feet high.

20. Manholes may be constructed of either cement or hard-burned brick laid in Portland-cement mortar, the latter, probably, being preferable. The foundation should consist of a layer of cement, the concrete being at least 6 inches thick. The walls, if of brick, should be laid in cement mortar, and should, also, be thoroughly plastered on the outside with the same mortar. They should never be less than 8 inches thick, and should be made double this thickness where large manholes are being constructed in busy streets. As the brickwork is laid up, the iron brackets

for supporting the cables around the sides should be built

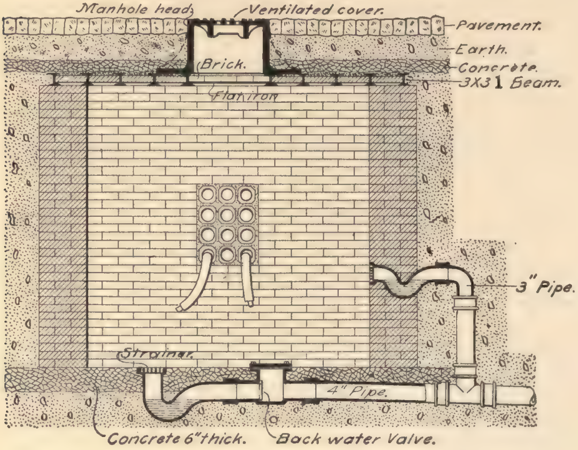


FIG. 17.

in. The roof should be of either arched brick or structural

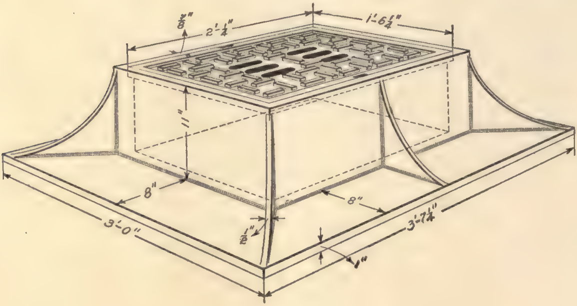


FIG. 18.

iron, supporting some form of cast-iron manhole cover of which there are several types on the market.

21. Fig. 17 shows a cross-section of a ventilated manhole well suited for ordinary power-distribution work. It has been found better, on the whole, to provide manholes

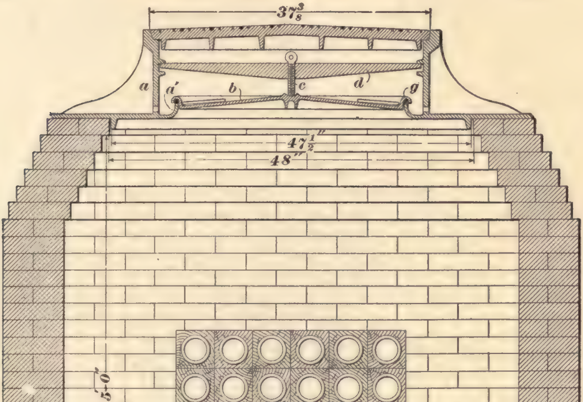


FIG. 19.

with ventilated covers and good sewer connections than to close them up tight, as was formerly done. If they are tightly sealed, gases are liable to accumulate and cause

explosions. In Fig. 17, the manhole is provided with two sewer connections, so that in case the bottom one gets clogged up, the water will be able to flow through the side connection instead of backing up into the ducts. Both connections are provided with traps to keep out the sewer gas and the bottom connection is equipped with a back-water valve to keep water from backing into the manhole. A removable cover is provided at the back-water valve, so that any dirt that accumulates may be cleaned out.

The roof of the manhole is made by laying $3'' \times 3''$ **I** beams across the top and filling between them with brick, the whole being covered with a layer of cement. The manhole cover may be either round or rectangular. Fig. 18 shows a rectangular manhole head with ventilated cover. Fig. 19 shows a manhole with a water-tight inner cover *b*, which is firmly clamped down by the screw *c* and cross-piece *d*. The joint is made water-tight by the gasket *g* pressing on the upturned flange *a'*.

DISTRIBUTION FROM MANHOLES.

22. As stated before, where the conduit system of underground distribution is used, the current is delivered by means of lead-covered cables that are drawn into the ducts after the conduit proper has been completed. These cables are drawn from manhole to manhole by means of a rope attached to the end of the cable. Fig. 20 shows one arrangement for drawing in cables.

23. Cables.—The construction of the cables themselves depends on the kind of service to which they are to be put. Two kinds of insulation are available—rubber and paper. With good rubber insulation, a small puncture in the lead sheath may not impair the insulation for some time, because the rubber is, to a large extent, proof against moisture. On the other hand, paper insulation will be damaged if the

lead sheath becomes punctured so as to admit moisture. Paper insulation is, however, cheaper than rubber, and if the cables are carefully installed will give excellent service. Fig. 21 shows a paper-insulated cable designed for 6,600-volt, three-phase transmission. The three conductors are insulated with paper wrapping to a thickness of $\frac{1}{8}$ inch.

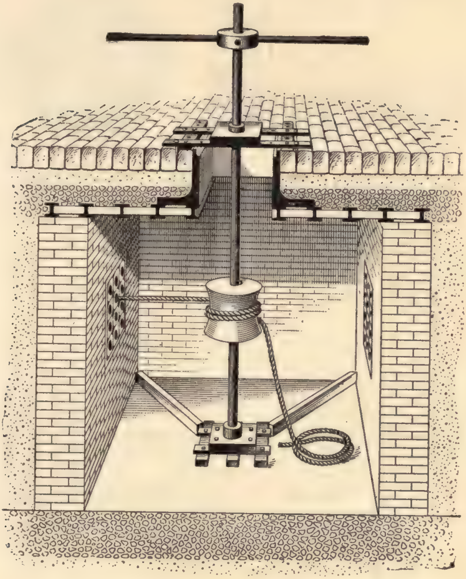


FIG. 20.

These three strands are then twisted together and covered with a wrapping of paper $\frac{1}{16}$ inch thick, over which the $\frac{1}{8}$-inch lead covering is forced. The paper is treated with insulating compound and the space between the strands, shown black in the figure, is filled with jute treated with insulating compound.

24. Connecting Cables.—In underground, electric-power distribution, it is important to have the various parts of the system so arranged that they can be disconnected, if necessary, because faults are liable to develop, and if the various sections can be readily disconnected, it makes the

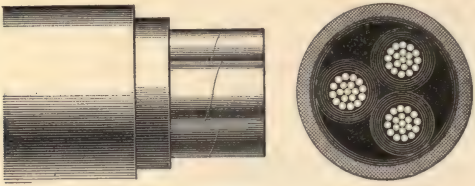


FIG. 21.

location of the defective portion very much easier to find. Also, when the defective part is located, it can easily be cut out without interfering with the operation of the remainder of the system. For ordinary low-pressure work,

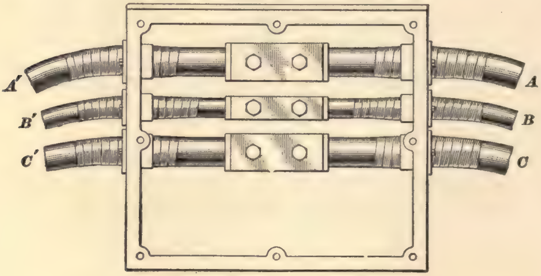


FIG. 22.

the various joints are usually made by means of **coupling boxes,** or **junction boxes.** These are placed on the side walls of the manholes and are made water-tight. Fig. 22 shows a coupling box. A, B, and C are the three main cables, or feeders, of a three-wire system that are to be

coupled to the three cables A', B', C'. The cables enter the cast-iron box through rubber gaskets that are clamped so as to make the box water-tight. Each cable is provided with a terminal on the end, and these terminals are connected together by pieces of copper bar securely clamped against the terminals by the bolts shown in the figure. The box is provided with a cover that is bolted against a rubber gasket. This box is merely intended for coupling the ends of the cables together and takes the place of permanent joints that could not readily be disconnected.

25. Junction Boxes.—The main cables, or feeders, running from the station terminate in the manholes, and it is necessary to have some convenient means of connecting

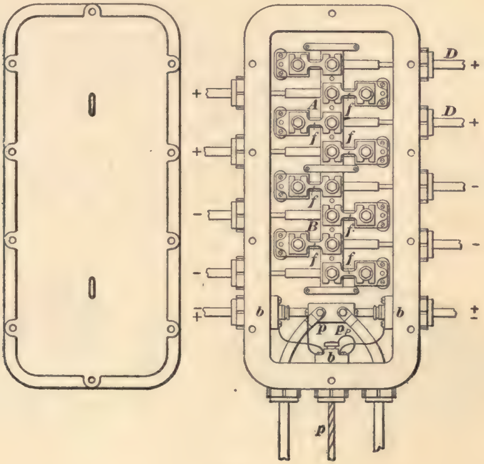


FIG. 23.

them to the various branch lines. This is done by means of junction boxes. Fig. 23 shows a junction box that is known as a *four-way box*, because it accommodates four positive and

four negative cables. The box is designed for use on low-pressure, three-wire work. *A* and *B* are the positive and negative bars, which are made of copper and are well insulated from each other. These bars connect across to the cable terminals through copper fuses *f*, so that in case a short circuit occurs on a line, these fuses will blow and thus prevent damage. The short neutral bar shown in the bottom of the box attaches directly to the cables, because it is not usually considered necessary or even desirable to place a fuse in the neutral. The small wires *p*, *p* are **pressure wires** that run back to the station and there connect to voltmeters, so that the voltage at the center of distribution, represented by the junction box, may be determined at any time. These pressure wires are protected by fuses placed in the small fuse receptacles *b*, *b*, *b*. Each pressure wire connects to one side of a cut-out *b* and the other sides connect to the +, −, and neutral bars. The cables pass into the box through water-tight rubber gaskets and the box is closed by a water-tight cover. Junction boxes are made in a large variety of forms for different kinds of service.

26. Service Boxes.—When the conduit system of distribution is used and where customers have to be supplied,

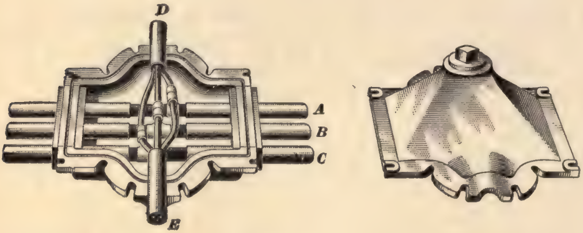


FIG. 24.

small **handholes** are provided wherever distributing points may be necessary. These are much smaller and shallower than manholes and only run down as far as the conduit.

In these handholes a **service box** is placed. Fig. 24 shows one style of service box with its cover removed. *A*, *B*, and *C* are the main cables that run straight through the box without being cut. *D*, *E* are the three-wire, branch-service cables, or tubes, for supplying current to the buildings. These are attached to the main cables by means of suitable clamps, and after the cover is bolted in position the box is filled with insulating compound. Fig. 25 shows another style of service box for use on the three-wire system. In this four-way box the main cables are fastened to terminals instead of passing straight through. Fig. 26 shows a handhole with its service box arranged for delivering current to overhead conductors. The main feeders, running from manhole to manhole, are placed in the lower tiers of conduits, and the service mains that run back from the manholes are run in the upper row, so that they will be accessible for the connection of service boxes.

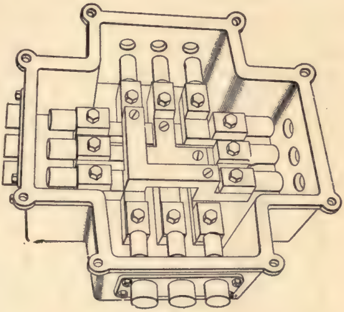


FIG. 25.

27. Joining Cables.—For low-pressure work, cables are usually joined in the manholes by means of coupling boxes or junction boxes. Sometimes, however, joints must be made without the use of these boxes, in which cases the job must be very carefully done.

First, the soldered end of the cable is cut off and the cable carefully examined for moisture. If a little moisture be present and there is still more than enough room for the joint, it is allowable to cut off another short length. If indications of moisture are still present, heat should be applied to the lead covering, starting from a distance and

proceeding along the cable to the end. Thus the moisture is driven out at the cut. When the use of torches is not allowed on account of gas in the manholes, hot insulating compound, such as boiling paraffin, may be poured over the cable. This process is known as boiling out. To ascertain whether moisture is present, the piece last cut off is stripped of its lead covering and plunged into hot insulating compound. If bubbles rise, moisture is still present.

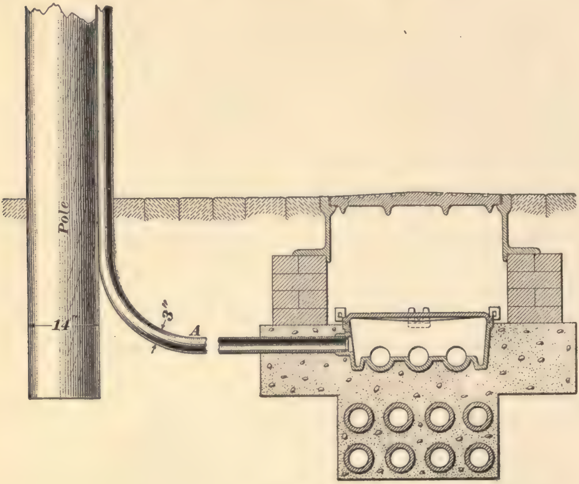


FIG. 26.

When all trace of moisture has disappeared, the lead covering is removed for a convenient length from each of the ends to be joined and the insulation is cut away for a shorter distance from the end, leaving a certain length beyond the lead. A lead tube of sufficient diameter to fit over the cable sheath and of a length great enough to cover the joint to be made is slipped over one end of the cable and back out of the way. Now, if the conductor be

small enough, the regulation telegraph joint is made and soldered. But if the conductor be stranded or of large cross-section, the ends are cut square, butted together, and soldered, and made much more secure by a copper sleeve, which is soldered over all. This sleeve is open at one side, so that solder may be run in until the strands are thoroughly saturated. The joint is now covered with insulating tape to the height of the lead covering.

A layer of paraffined paper may be wrapped on over this or, as is sometimes done, a mica tube may be slipped over the joint. The lead tube is then slid along the cable so as

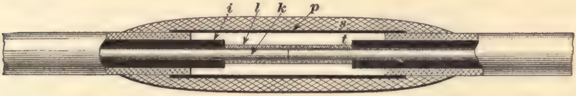


FIG. 27.

to cover the joint. The ends of this are then secured to the cable sheath by a wiped solder joint, thus making the sheath again continuous.

A section of such a joint is shown in Fig. 27, where *i* is the insulation, *l* is the copper sleeve, *k* is the conductor, *p* is the paper wrapping or mica sleeve, and *s* is the lead sleeve with a wiped solder joint. The space *t* is wound with insulating tape. For many of the larger cables, the sleeve *s* is made considerably larger in diameter than the cable sheath, so as to leave a space that is afterwards filled with compound. Details as to the methods of splicing and handling the various kinds of cables are furnished by the manufacturers.

28. High-Tension Joint.—In most cases where cables are called upon to stand a high pressure, they are joined somewhat as described in the last article and very carefully insulated, so that the insulation of the joint may be as good as that of the rest of the cable. Mechanical couplings and junction boxes are not used very extensively for this class

of work on account of the difficulty of securing high enough insulation, and also on account of the difficulty of keeping moisture out of the cable. Figs. 28 and 29 show the Tailleur high-tension coupling that has been successfully used on pressures not exceeding 5,000 volts.

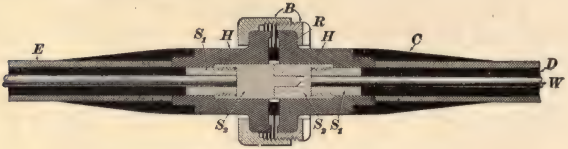


FIG. 28.

Fig. 28 shows the joint made and Fig. 29 shows it broken To make the joint, the lead armor, or sheath, E is stripped a sufficient distance from the end to permit the slipping on of the hard-rubber jacket H, after the terminal S_1 has been soldered to the copper conductor W, first tinning the end of the copper conductor W and also the terminal S_1. One part of the hard-rubber jacket H is slipped through one

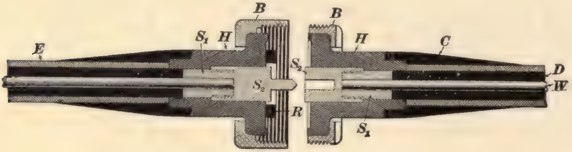


FIG. 29.

part of the brass coupling B, then the hard-rubber jacket H, with the brass coupling B, is passed over the terminal S_1, and the piece S_2 is screwed on contact terminal S_1. Pure rubber, which generally comes in sheets, is cut into strips about 1 inch or $1\frac{1}{4}$ inches wide, and the joint is taped as shown at C, allowing the tape to lap over the cable armor about 1 inch. The rubber tape is afterwards covered with

other tape and then treated with compound. The soft-rubber ring *R* is then placed as shown, and the joint clamped tightly together, after which the whole joint is covered with tape and insulating compound.

EDISON UNDERGROUND-TUBE SYSTEM.

29. The **Edison underground-tube system** differs from the conduits previously described in that the conductors are placed in iron tubes that are buried in the ground. The conductors are, therefore, not removable. This arrangement has been used extensively by illuminating and power companies in the larger cities. The conductors themselves are usually in the shape of round copper rods; the main tubes are designed for use on the three-wire system and are, therefore provided with three rods, as shown in the section

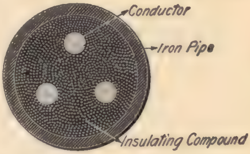


FIG. 30.

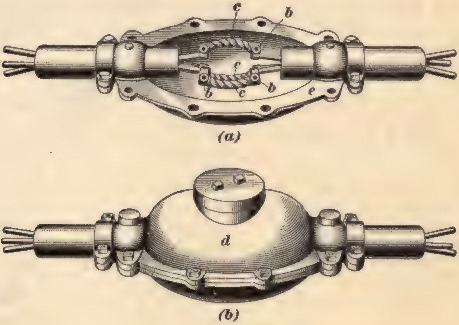
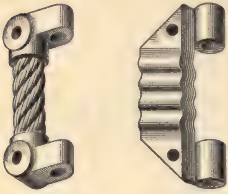


FIG. 31.

in Fig. 30. Each rod is wound with an open spiral of rope that serves to keep the rods separated in case the insulating

material in the tubes should become soft. After the rods have been provided with the rope spiral, they are bound together by means of a wrapping of rope and inserted in the iron pipe, the rods projecting for a short distance at each end. The whole tube is then filled with an insulating compound that becomes hard when cold. The tubes are made in 20-foot lengths and are laid in the ground about 30 inches below the surface of the pavement. They are joined together by means of the coupling boxes shown in Fig. 31 (*a*) and (*b*). Fig. 31 (*a*) shows the lower half of the box only, with the main tubes entering each end. The conductors are connected together by means of short, flexible, copper cables *c*, *c*, *c*, provided with lugs *b*, *b*, that fit over the rods and are soldered in place. A cover *d* similar to the lower half *e* is then placed in position and the two



(*a*) (*b*)

FIG. 32.

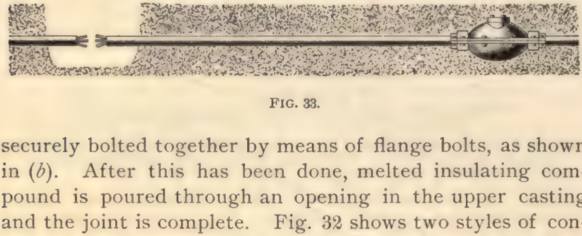


FIG. 33.

securely bolted together by means of flange bolts, as shown in (*b*). After this has been done, melted insulating compound is poured through an opening in the upper casting and the joint is complete. Fig. 32 shows two styles of connectors used for connecting the ends of the rods; (*a*) is a stranded copper cable with terminals and (*b*) is a laminated copper connector. Fig. 33 indicates a length of pipe with its couplings.

30. Where branches are taken off the mains, **T** coupling boxes are used, as indicated in Fig. 34. This box, also, is filled with insulating compound that soon becomes hard and prevents the flexible connections from coming in contact

with one another. At the centers of distribution (usually a street intersection) junction boxes are provided. These correspond to the manholes of the conduit system. The main supply wires, or feeders, run from the station to these junction boxes, whence the mains are run to the various districts where light or power is supplied. Fig. 35 shows one of these junction boxes. The tubes enter at the lower part of the cast-iron box, and the mains are connected to

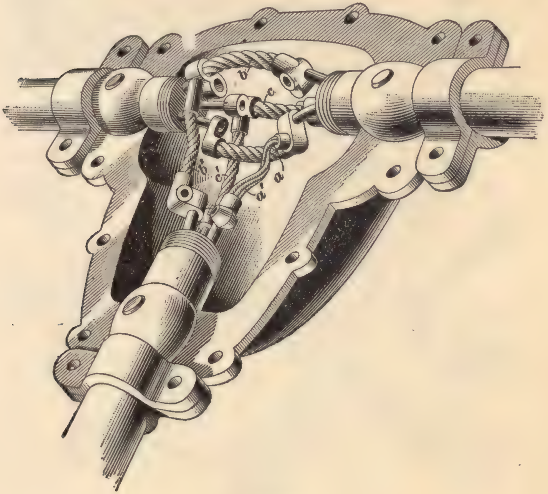


Fig. 34.

the feeders through fuses that bridge over between the rings shown at the top. These fuses must be proportioned according to the size of the conductor in the tube to which they are connected. If the conductors are overloaded, they will heat and destroy the insulation. The allowable carrying capacities of underground tubes and cables have been made the subject of a large number of tests by the manufacturers, who furnish tables giving the limit to which

their cables or tubes may be loaded with safety. The junction box shown in Fig. 35 is made water-tight by clamping down the cover by means of the studs *b*, *b* and the whole is then covered with a cast-iron plate resting in the groove *c* and coming flush with the street surface.

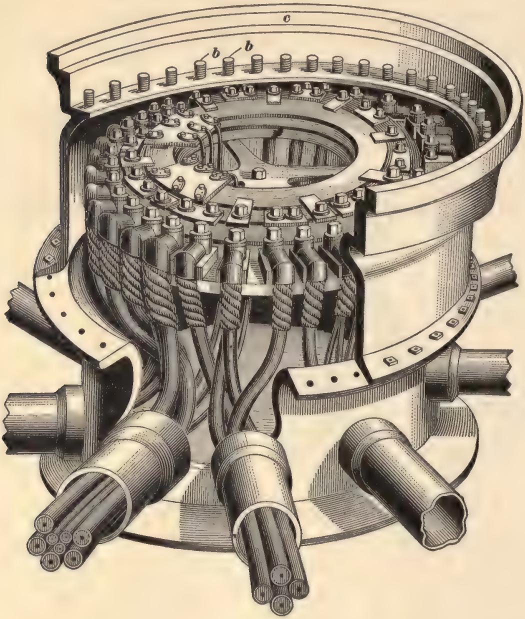


FIG. 35.

31. The underground tubes and fittings are rather expensive, but they are comparatively cheap to install, as all that is necessary is to dig a shallow trench and lay the tubes in the ground. This system has the disadvantage that if any trouble occurs it is somewhat awkward to get at it, as the conductors cannot be pulled out as in a conduit

system. When trouble occurs, the usual method of procedure is to dig a hole at one of the couplings and separate the ends. By making a few breaks in this way at different points, the section in which the ground or short circuit is present can soon be located and the defective length of tube removed.

32. The Edison tube system is not now used as largely as it once was for the main distributing lines or feeders. The present practice is to carry the main conductors from the station to the various distributing points in ducts, so that they may be drawn out if necessary. The tube system is, however, well adapted for the distributing mains, and is largely used for this purpose, because it allows service connections to be made easily and cheaply. Table I gives the cross-section of the rods used in the standard

TABLE I.

CARRYING CAPACITY OF UNDERGROUND TUBES.

Size of Each Conductor in Circular Mils.	Maximum Current in Each of Two Conductors.
41,000	100
80,000	200
100,000	235
120,000	260
150,000	295
200,000	350
250,000	400
300,000	450
350,000	495
400,000	540
450,000	580
500,000	620

tubes that are now used for distributing mains. Each tube has three conductors of the same size and the table shows the allowable current when two of the conductors are loaded. If the system is balanced, the third wire will carry but a small current.

TESTS.

33. In testing lines or apparatus, it is frequently necessary to make rough tests that will show whether or not circuits are continuous, broken, crossed, grounded, or properly insulated. These tests do not require accurate measurements, they being merely for the purpose of determining the existence of a faulty condition.

34. Magneto Testing Set.—The most common, and probably, all things considered, the most useful, form of testing instrument for rough testing is that consisting of a magneto generator and bell mounted compactly in a box provided with a strap for convenience in carrying.

TESTING LINES FOR FAULTS.

35. Faults on a line may be of two kinds: the line may be entirely broken, or it may be unbroken but in contact with some other conductor or with the ground. The former fault is termed a **break**; the latter a **cross** or **ground.** A break may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall so as to form a cross or ground. A cross or ground may be of such low resistance as to form a short circuit or it may possess high resistance, thus forming what is called a **leak.** There are a number of different methods used for locating faults, and as those most suitable depend to a considerable extent on the kind of work for which the lines are used, most of the points relating to testing will be left until the different subjects with which they are connected are considered.

36. Continuity Tests.—In testing wires for continuity, the terminals of the magneto set should be connected to the terminals of the wire and the generator operated. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and in cables, because it may be that the electrostatic capacity of the line wires themselves will be sufficient to allow enough current to flow through the ringer to operate it, even though the line, or lines, is open at some distant point.

37. Testing for Crosses or Grounds.—In testing a line for crosses or grounds, one terminal of the magneto set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings, and also the pull of the generator in turning, will indicate, in some measure, the extent of this cross.

38. Here, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists if the line under test is a very long one. The insulation may be perfect and yet permit a sufficient current to pass to and from the line through the bell to cause it to ring, these currents, of course, being due to the static capacity of the line itself. In testing very long lines or comparatively short lines of cable, the magneto set must be used with caution and intelligence on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied upon as being accurate.

Magneto testing sets are commonly wound in such manner that the generator will ring its own bell through a

resistance of about 25,000 ohms. They may, however, be arranged to ring only through 10,000 ohms, or where especially desired, through from 50,000 to 75,000 ohms. The first figure mentioned—25,000 ohms—is probably the one best adapted for all-round testing work.

CURRENT DETECTOR GALVANOMETER.

39. In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise in testing with a magneto set, a cheap form of galvanometer for detecting currents, called a **detector galvanometer,** may be used. In testing for grounds or crosses, the galvanometer should be connected in series with several cells of battery and one terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected successively to the ground and to adjoining wires. A sudden deflection of the galvanometer needle will take place whenever the circuit is first closed, this being due to the rush of current into the wire that is necessary to charge it. If the insulation is good, the needle of the galvanometer will soon return to zero; but if a leak exists from a line to the ground or the other wire with which it is being tested, the galvanometer needle will remain permanently deflected.

In testing for continuity, the distant end of the line should be grounded or connected with another wire that is known to be good, and the galvanometer and battery applied, either between the wire under test and the ground or the wire under test and the good wire. In this case, a permanent deflection of the galvanometer needle will denote that the wire is continuous, while if the needle returns to zero it is an indication of a broken wire.

40. Test for Insulation Resistance.—One thing that it is important to know about lines is the state of their insulation. In order to determine this, measurements of the

insulation resistance between the line and ground must be made, and if this resistance is found to be dangerously low, the trouble should at once be looked up and remedied. One of the most convenient methods for measuring insulation resistance is by means of a good high-resistance voltmeter. The voltmeter is much easier to handle than a reflecting galvanometer, and if the resistance of the voltmeter is known, insulation resistance measurements may be made with very little trouble. Suppose in Fig. 36 we wish to measure the insulation resistance of the line $A\,A$. The voltmeter is first connected across the lines at V in the usual

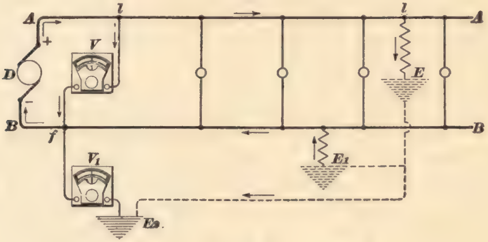


FIG. 36.

manner and the voltage of the dynamo D obtained. Call this reading V. As soon as possible after taking the reading V, the voltmeter is connected between the line $B\,B$ and the ground, as shown at V_1, and a reading V_1 obtained. In this case all the current that goes through the voltmeter passes from l, through the insulation, to E and thence through the ground and the voltmeter V_1 to f. It is evident that if the insulation resistance of the line $A\,A$ is very high, very little current will flow through the voltmeter, and a small deflection will be the result. If the resistance r of the voltmeter is known, then the insulation resistance of the line will be

$$R = \frac{(V - V_1)r}{V_1}, \qquad (1.)$$

provided no ground exists on the dynamo D.

EXAMPLE.—The insulation resistance of an electric-light main was tested by means of a Weston voltmeter having a resistance of 18,000 ohms. When connected across the lines, the voltmeter gave a reading of 110 volts. When one line was connected to ground through the voltmeter, the reading was only 4 volts. What was the insulation resistance of the other line?

SOLUTION.—We have by formula **1**,

$$R = \frac{(110 - 4)\,18{,}000}{4}$$

$$= \frac{106 \times 18{,}000}{4}$$

$$= 477{,}000 \text{ ohms. Ans.}$$

NOTE.—The insulation resistance of lines is usually expressed in megohms, 1 megohm being equal to 1,000,000 ohms. The resistance of the line in this case would therefore be .477 megohm.

TESTS FOR GROUNDS OR CROSSES.

41. Varley Loop Test.—One of the commonest methods for locating a ground or cross is by means of the Varley loop test. In Fig. 37, G is a sensitive galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; $A\,B$ and $A\,C$ are the ratio arms and $C\,D$ the

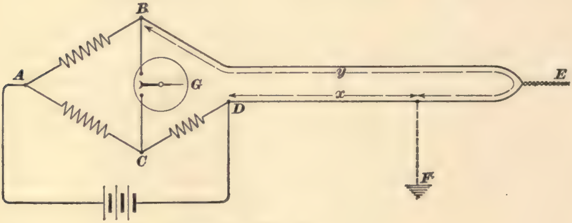


FIG. 37.

rheostat or balance arm of the bridge. $D\,E$ is the faulty line and F the location of the fault. The two lines should be connected together at E and the ends of the loop $B\,E\,D$, so formed, connected across the terminals of the bridge as

the unknown resistance. Call y the resistance of the loop from B to F and x the resistance from D to F. With the battery connected between A and D, as in the ordinary method of using the Wheatstone bridge, balance the bridge. This will give, by working out the unknown resistance in the usual manner, a resistance R equal to the sum of the resistances of the two wires forming the loop; that is,

$$R = y + x.$$

Or, the resistance R of the whole loop may be calculated, because the length and size of the line wire are known.

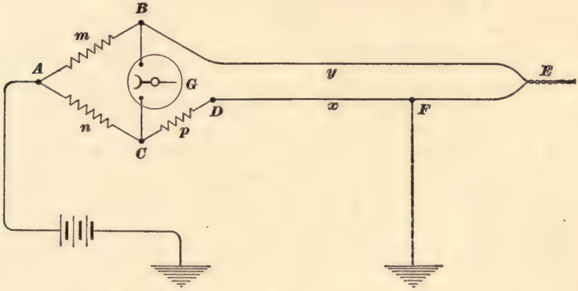


FIG. 38.

Now disconnect the battery from D and connect it to the ground, as shown in Fig. 38. Then balance the bridge again, and the resistance x may be obtained by means of the following formula :

$$x = \frac{nR - mp}{m + n}, \qquad (2.)$$

in which m, n, and p are the values of the resistances in the arms $A\,B$, $A\,C$, and $C\,D$. After obtaining the resistance x from D to the fault F along the line $D\,E$ by means of formula **2**, the distance (in feet or miles) from the testing end D to the fault F may be obtained by dividing this resistance x by the resistance of a unit length (a foot or a mile, as the

case may be) of the line wire DE. The result obtained by this test is independent of the resistance at the fault between the line and the ground.

EXAMPLE.—A ground occurred on a conductor of a cable 10,000 feet long composed of three No. 10 wires. One good wire was used to complete the loop. On testing with one end of the battery grounded as in Fig. 38, the bridge was balanced with the following resistances: $m = 10$ ohms, $n = 1{,}000$ ohms, $p = 1{,}642$ ohms. Where was the ground, the resistance per 1,000 feet of the conductor being .9972 ohm?

SOLUTION.—The length of the loop formed by joining the two wires of the cable at the distant end will be 20,000 feet;

hence, $$R = 20 \times .9972 = 19.944,$$

and $$x = \frac{1{,}000 \times 19.944 - 10 \times 1{,}642}{1{,}000 + 10} = 3.4891.$$

Hence the distance of the fault from the testing station must be

$$\frac{3.4891}{.9972} \times 1{,}000 = 3{,}498.9 \text{ ft. Ans.}$$

42. Locating a Partial Ground Without an Available Good Wire.—The following method for locating a partial ground or escape is rather unreliable in practice, because the resistance of the partial ground may change between the two measurements, and so give a more or less

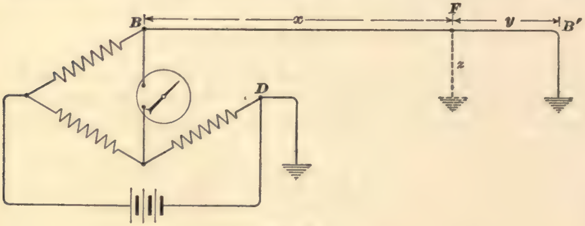


FIG. 39.

incorrect result. However, it is about the only way where there is no available good wire and when the tests must be made from one end only. The normal resistance of the line must be known from some previous measurement, unless it can be calculated from the length and size of the

wire. Let this resistance be a; then measure the resistance of the line $B B'$, with the distant end B' grounded as shown in Fig. 39, and call this c. Also measure the resistance

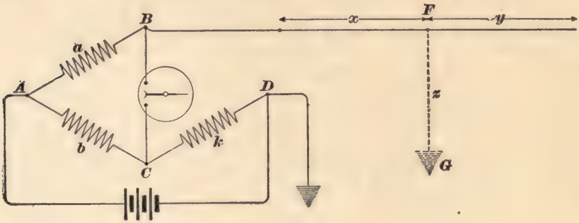


FIG. 40.

with the distant end open, as in Fig. 40, and call this b ohms. Then the resistance x to the partial ground from the testing station is given by the following formula:

$$x = c - \sqrt{(b - c)\,(a - c)}. \qquad \textbf{(3.)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurements or by a calculation from its size, length, and a table of resistances for the kind of wire under consideration, the distance to the grounded point may be obtained.

43. To Locate a Cross by the Varley Loop Method.—First insulate the distant ends of the two crossed

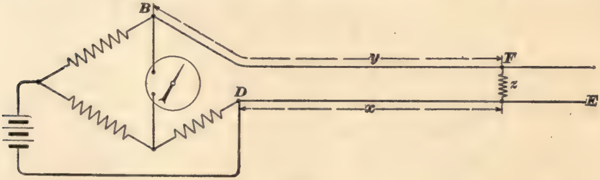


FIG. 41.

wires. Then connect as shown in Fig. 41 and measure the resistance from D to B through the cross F. Let the

resistance of the cross be z ohms and the resistance found by balancing the bridge be R ohms.

Then, $$R = x + y + z. \qquad (1)$$

Now ground either wire, say $D\,E$, anywhere beyond the

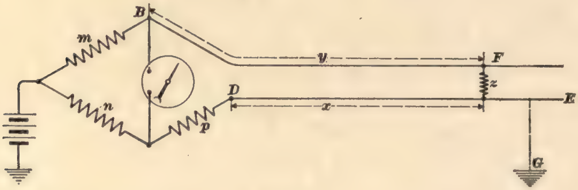


FIG. 42.

cross, and connect as shown in Fig. 42. When the bridge is again balanced, we have

$$\frac{m}{n} = \frac{y + z}{p + x}. \qquad (2)$$

From equations (1) and (2), we get

$$x = \frac{n\,R - m\,p}{m + n}.$$

This is the same as formula **2.** By dividing x by the resistance of the wire $D\,E$ per unit length, we have the distance from D to the fault along the wire $D\,E$.

PROTECTION OF LINES FROM LIGHTNING.

44. Overhead lines are always liable to accumulate a certain charge of static electricity even if they are not actually struck by lightning. Long transmission lines should be well protected against lightning, as they frequently run through exposed and mountainous country. If these

high-pressure discharges travel along the line and get into the dynamos at the power station, they are almost sure to puncture the insulation of the machines and result in a burn-out. To guard against this, lightning arresters should be provided.

It was formerly thought sufficient to place a lightning arrester on each line at the station, trusting to these to lead any discharge to the ground. However, this was found to be an unsafe practice. It is now generally admitted that the safest plan is to distribute a number of arresters at intervals along the line, so that any charge that may happen to accumulate will be led to ground before it reaches the station. There are a large number of different types of lightning arresters in use that accomplish their purpose more or less perfectly. They offer a great deal of protection if properly installed; but, as is well known, lightning is very erratic in its behavior and often does damage in spite of the lightning arresters. This is no reason, however, why every line should not be equipped with them at intervals of about every half mile at least. What is given here is intended to apply to lightning arresters in a general way, and the description of special types will be taken up later in connection with the special lines of work to which they are adapted. The arresters for any given line must be selected with reference to the kind of circuit on which they are to be used, and descriptions of some of the more important types will be given in connection with the subjects of *Electric Lighting* and *Electric Railways*. For the present we will confine our attention to general principles.

45. Simple Lightning Arrester.—The term **lightning arrester** does not correctly express the use of these devices, because they do not arrest the discharge coming in over the line; they merely divert the charge by providing a path to the ground that the lightning will take in preference to passing into the dynamo and making a path for itself to the ground by puncturing the insulation of the machine.

In order to understand the action of the lightning arrester, it must be remembered that a lightning discharge is oscillatory in character, i. e., it is rapidly changing in a manner somewhat similar to an alternating current, the frequency of which is exceedingly high. On account of its rapidly changing character, lightning will not pass through an inductive path if there is a non-inductive path provided for it. The armature of a dynamo always possesses a certain amount of self-induction, and a comparatively small amount of self-induction will offer a very high resistance to a lightning discharge. Every coil of wire has some self-induction, and a lightning discharge will jump across an air gap that has no self-induction before it will pass through a coil, even if the ohmic resistance of the coil is very low. Suppose we have a short air gap $d\ e$, Fig. 43, and a coil B arranged as shown. If terminal C is connected to the ground and a discharge comes in over the line A, it

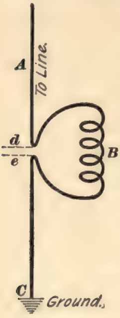


Fig. 43.

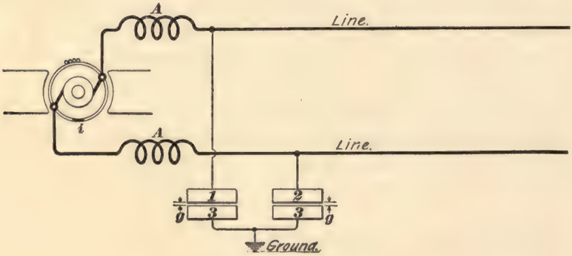


Fig. 44.

will jump the gap $d\ e$ rather than pass through the coil B, even though this coil is made of heavy wire and contains but few turns. The simplest form of lightning arrester is that shown in Fig. 44. A pair of plates *1*, *2* are connected one to each line and are separated by a small gap g from

two other plates *3*, *3* that are connected to the ground. The gap in the arrester should be more easily jumped across by the discharge than the thinnest insulation *i* on the dynamo, otherwise the discharge will jump through the insulation to the ground instead of jumping across the air gap. The air gap must, of course, be long enough that the pressure generated by the dynamo itself will not be able to jump across it. For pressures up to 500 volts a gap of $\frac{1}{32}$ inch should be sufficient, and a gap of this length offers considerably less resistance to the discharge than the insulation on the dynamo.

46. Reactance, or Kicking, Coils.—In order to make more certain that the discharge will pass through the arrester, **kicking coils,** or **reactance coils,** are often inserted between the arrester and the dynamo. A kicking coil, or reactance coil, is a coil of wire consisting of a few turns inserted in the circuit between the arrester and the apparatus to be protected, as shown at *A A*, Fig. 44. These coils have a certain amount of self-induction, and the consequence is that when a discharge comes in over the line, they offer a high resistance to its passing into the dynamos. They choke back the discharge and force it to pass to the ground by jumping the air gap. Fig. 45 shows a typical kicking coil.

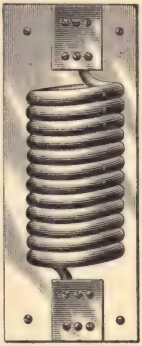


FIG. 45.

47. Suppression of Arcing.—The simple arrangement of air gaps shown in Fig. 44 will hardly work on electric-light and power circuits for the following reason: If a discharge comes in over both the lines at once, as is quite likely to happen, because the lines usually run side by side, an arc will be formed across both the gaps, and current from the dynamo will follow the arc. The result will then be

practically a short circuit on the dynamo, and such a large current will flow that the plates or contact points of the arrester will be destroyed. It is necessary, then, to have in addition to the air gap some means for suppressing or blowing out the arc as soon as it is formed. It is also necessary that as soon as the discharge has passed, the arrester will be in condition for the next discharge. Generally speaking, the arc from a continuous-current machine is not as easily extinguished as that from an alternator; probably because every time the current passes through its zero value it loses some of its ability to hold the arc. A large number of different types of arresters have been brought out. In some cases, the arc is broken by being drawn out until it can be no longer maintained; in others, the air gap is so placed that it will be surrounded by a magnetic field, so that when the arc is formed it is forced across the field in just the same way that a wire carrying a current moves across the magnetic field in a motor. The result is that the arc is stretched out until it is broken. The magnet blows out the arc almost instantaneously. Another method for suppressing the arc following the discharge is to make it occur in a confined space so that it will be smothered out. Still another method is to make the cylinder or plates between which the arc jumps of a so-called non-arcing metal. The vapor of this metal offers a high resistance to the discharge, and, hence, the dynamo is unable to maintain the arc. Some arresters will work on either direct or alternating current; but, generally speaking, the arrester has to be selected with reference to the voltage of the circuit on which it is to be used and also with reference to the kind of current, i. e., direct or alternating.

48. Ground Connections for Lightning Arresters.—As stated above, it is best to be on the safe side and distribute lightning arresters along the line as well as placing them in the station. These arresters will, however, be of little or no use if good ground connections are not provided for them. The following methods of making

ground connections are recommended by the Westinghouse Company.

49. The method of making the ground connection for a line or pole lightning arrester is shown in Fig. 46. A galvanized-iron pipe is driven well into the ground and the top of it surrounded by coke, which retains moisture; the wire is run down the pole and connected to the top of the pipe as indicated. The wire is sometimes encased in galvanized-iron pipe for about 6 feet from the base of the pole. If this is done, it is well to solder the ground wire to this pipe at *a*. When a number of arresters are installed on the lines entering the station, special care should be taken in making the ground connection, otherwise the whole lightning-arrester installation may be practically useless. The following method of making the ground connection is recommended: A hole 6 feet square is dug 5 or 6 feet deep in a location as near the arresters as possible, preferably directly under them. The bottom of this hole is then covered with charcoal or coke (crushed to about pea size) to a depth of about 2 feet. On top of this is laid a tinned, copper sheet, about 5 ft. × 5 ft., with the ground wire (about No. 0 B. & S.) soldered completely across it. The plate is then covered with a 2-foot layer of coke or charcoal and the remainder of the hole filled with earth, running

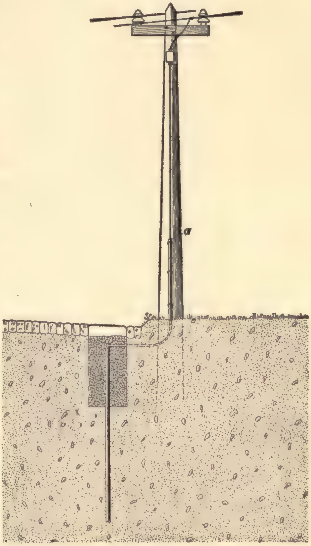


FIG. 46.

water being used to settle it. This will give a good ground, if made in good, rich soil. It will not give a good ground in rock, sand, or gravel. Sometimes grounds are made by putting the ground plate in a running stream. This, however, does not give as good a ground as is commonly supposed, because running water is not a particularly good conductor and the beds of streams very often consist of rock. When lightning arresters are installed, all wires leading to and from them should be as straight as possible. Bends act more or less like a choke coil and tend to keep the discharge from passing off by way of the arrester.

50. For long-distance, high-tension lines, another method for protection from lightning has been adopted in some cases. Barbed wire is run along the tops of the poles and is thoroughly grounded at intervals. This wire collects the static charges and leads them to the ground. On these very high-pressure lines, it is necessary to use a number of air gaps in series, so that the pressure of the line will not of itself be able to set up a current to the ground. This usually means that either a special form of arrester with a large number of gaps in series, or a number of regular arresters connected in series, must be used. The use of the barbed wire does away with the need of line arresters. It is claimed that it has given very good results in some cases, while in others the lightning arresters have been preferred.

51. Lightning Arresters on Underground Lines.—It would hardly seem necessary to equip lines that are wholly underground with lightning arresters. While it is true that such lines are not at all in danger from ordinary lightning discharges, nevertheless it has been found that when underground cables are used in connection with high-tension transmission systems, static charges of electricity gradually accumulate; and if these charges are not allowed to pass off to the ground, they may puncture the insulation of the cables. The lines are, therefore, very often protected by lightning arresters or static dischargers that are similar in construction to a lightning arrester, to

allow the escape of these static charges to earth. For example, the underground distributing system of the Metropolitan Street Railway Company, of New York, is fully equipped with lightning arresters, although no part of the system is above ground.

STORAGE BATTERIES.

52. The *storage battery*, or *accumulator*, is now so largely used in connection with electric-transmission plants of various kinds that a general description of its action will be given here. Its use in connection with special lines of work will be considered more fully when the subjects of *Electric Lighting* and *Electric Railways* are taken up.

53. Accumulators, storage batteries, or **secondary batteries** are those in which a chemical change is brought about by sending current through the cell from some outside source, the chemical compounds so formed being capable of delivering electrical energy when changing back to their former state when the cell is discharged. The storage battery does not, therefore, store up electricity; it is simply a cell, in which the changes brought about by the charging current put the cell in a position to deliver electricity in much the same way as any ordinary primary battery. A large number of different types of storage cell have been devised, but the only kind that has come into extensive use is the lead accumulator. In this cell, lead in some form is used for both the positive and negative plates, and the solution, or electrolyte, is a mixture of sulphuric acid and water.

54. Fig. 47 shows a typical storage cell made by the Electric Storage Battery Company and known as the **chloride accumulator.** These cells can be obtained in a variety of sizes from the small type, having only three plates (two negative and one positive), to the very large cells used in connection with central stations and substations. The cell shown is mounted in a glass jar. For very large

cells wooden tanks lined with lead are used, while for portable batteries the jars are made of hard rubber.

55. Positive and Negative Plates.—In Fig. 47, *a*, *a*, *a* are the positive plates and *b*, *b* the negative plates. Before going further, it may be well to point out just what is meant by the positive and negative plates of a storage battery. So far as appearance goes, the two plates may look very much alike, especially when the cell is discharged, but the **positive** plate is always the one at which the current flows *out* when the cell is discharging and *in* when it is charging. In charging a battery, one must always be sure to get the positive pole of the battery connected to the *positive* pole of the dynamo, so that the *charging* current will flow *in* at the positive pole. When the charging current is discontinued and the cell allowed to supply current to a circuit, the *discharging* current will flow *out* from the positive pole of the cell. The positive plates are, or should be, marked,

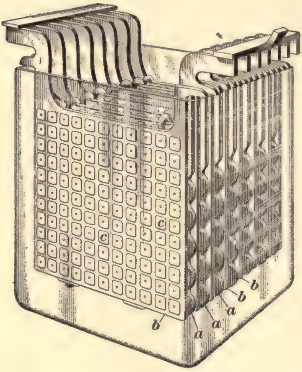


Fig. 47.

so that there will be no danger of incorrectly connecting the cells. When a pole indicator is not at hand, the polarity may always be found by connecting a wire to each pole and dipping the ends into a dilute solution of sulphuric acid. The wire from which the greater number of bubbles is given is connected to the negative pole. When connecting cells in series, care should be taken to see that the positive pole of one cell is connected to the negative pole of the next. Any person that has worked around storage cells for any length of time can tell the positive plates from the negative by their dark-brown color.

56. The complete chemical reactions that take place in a storage battery are complicated and many of them are not as yet well understood. When the cell is charged, the principal action is the formation of lead peroxide on the positive plate and spongy lead at the negative. Lead peroxide is a chemical compound consisting of 1 atom of lead and 2 atoms of oxygen; its chemical formula is PbO_2. This lead peroxide gives the positive plates the dark-brown color that they have when the cells are fully charged. When the cell is discharged, the lead peroxide gradually changes to lead sulphate and the metallic lead on the negative plate is also changed to lead sulphate. Lead sulphate $PbSO_4$ is formed by the action of the sulphuric acid in the electrolyte of the cell on the spongy lead. These chemical changes are repeated over and over as the cell is charged and discharged.

57. In Fig. 47, the plugs *c*, *c* seen in the negative plate are the portions of the plate that take part in the action of the cell. The framework, or surrounding grid, serves to hold the active material in place. When the cell is charged, these plugs are reduced to spongy lead. In the positive plate, the active material is placed in round holes, each of which contains a plug made of corrugated lead ribbon curled into spiral form. This lead ribbon, after being fixed in place, is converted into lead peroxide, and thus forms the active material of the positive plate.

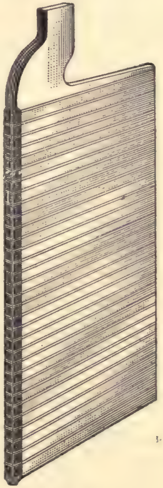


Fig. 48.

58. In some batteries, the active material is formed by means of chemical action on the plate itself and is not held in holes or pasted on the supporting grid. This was the method adopted by Planté, the originator of the storage battery. The pasted plate was brought out later by Faure. The Willard plate,

Fig. 48, is an example of one where the active material is formed on the plate itself. It consists of a lead plate provided with deep, narrow grooves, as shown. These grooves incline upwards and make the plate present a very large surface to the action of the electrolyte. The lead peroxide is formed on these plates by means of chemical action, and, as the grooves incline upwards, there is little chance for any of the material to become detached and fall out. Fig. 49 shows a cell consisting of a number of these plates mounted in a sealed hard-rubber jar so that the cell will be portable. Cells of this kind are designed for use on electric vehicles. The plates are separated by a perforated rubber plate that precludes any possibility of their coming in contact with one another.

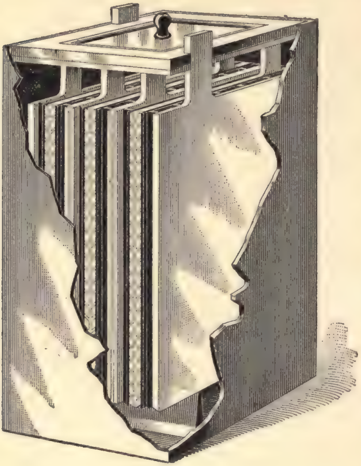


FIG. 49.

59. Rating of Storage Cells.—The capacity of a storage cell is generally given as so many *ampere-hours.* Thus, a cell that can deliver normally a current of 10 amperes for a period of 8 hours will have a capacity of 80 ampere-hours. If a cell is discharged at a rate higher than that for which it is designed, its output will be diminished. For example, in the above case, if the cell were made to deliver 16 amperes instead of 10, it would not keep up its discharge for 5 hours so as to give its total capacity of 80 ampere-hours. It does not pay in any event to take a larger current

from a cell than that for which it is designed, as it only results in a low efficiency and is liable to buckle or disintegrate the plates. The ampere-hour output of a cell is obtained by multiplying the average current in amperes by the time in hours during which the current is delivered.

The capacity of a cell in *watt-hours* is obtained by multiplying the average number of watts delivered by the number of hours. The *efficiency* of a cell is the ratio of the watt-hours delivered to the watt-hours supplied. This gives the true efficiency of the cell, although the ampere-hour efficiency, i. e., the ratio of the ampere-hours delivered to the ampere-hours supplied, is often taken as the efficiency of the cell. This would be correct if the voltage at charging were the same as when discharging, but such is not the case. The ampere-hour efficiency may be as high as 95 per cent., while the watt-hour efficiency is usually from 75 to 85 per cent. and represents the true efficiency of the battery. Small cells have a capacity of about 3 ampere-hours per pound of total weight, while large central-station cells may run as high as 6 to 7 ampere-hours per pound. An ordinary battery will weigh anywhere from 120 to 180 pounds per horsepower-hour capacity.

60. Voltage of Storage Cells.—The voltage required for charging a storage cell varies from 2 to 2.5 volts per cell. The voltage required gradually increases as the cell becomes charged. The voltage obtained at the discharge is from 2.2 to 1.8 volts, the pressure falling off as the cells become discharged. The difference between the voltage required to charge a storage battery and that obtained at the discharge is due largely to the internal resistance of the cells; thus it will now be readily seen why the watt-hour efficiency may be considerably less than the ampere-hour efficiency.

If we wish to charge 50 cells in series, the dynamo must be capable of furnishing $50 \times 2 = 100$ volts at the beginning of the charging, and this voltage must be increased to $50 \times 2.5 = 125$ volts as the cells become fully charged.

This is usually done by cutting resistance out of the field of the dynamo as the charging process proceeds. If only 20 cells, say, are to be charged, we will require from 40 to 50 volts; and if they are to be charged from a 100-volt dynamo, enough resistance must be inserted in series with them to take up the extra 60 to 50 volts. Hence, if the charging current were, say, 5 amperes, there should be at least $\frac{60}{5} = 12$ ohms resistance in series. If this were not used, the charging current would be excessive and the cells would be injured. Cells should not be discharged to such an extent that their pressure falls below 1.8 volts.

CARE AND OPERATION OF STORAGE CELLS.

61. Installation.—Cells should be installed in a room where the ventilation is good and where they may be easily inspected. They are generally mounted on a heavy framework that has been painted with acid-proof paint, and if the space is limited, are arranged in two or more tiers. Storage cells are heavy and the framework should be very substantial. It is necessary to watch the cells to see if any of the plates get into bad condition, also to test the condition of the electrolyte and renew it when necessary. It is important, therefore, that the cells shall be so arranged that the attendant can readily move around among them. The cells should be well insulated, otherwise the acid film that is sure to accumulate sooner or later may result in considerable leakage. It is a common practice to set each cell in a shallow tray about half full of sand and then support this tray on insulators. Fig. 50 shows an oil insulator that has been largely used for this purpose. It is made in halves and oil is placed in the lower half, as shown. The surface of the oil offers a high resistance to any leakage that may tend to

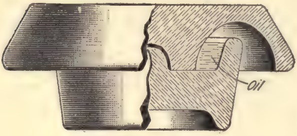


FIG. 50.

occur between the cell and the supporting framework. The cells are nearly always joined to each other by burning, or fusing, the lead terminals together. Soldering is not, as a rule, satisfactory or permanent. Mechanical clamping connections are not generally favored, for they do not give as low a resistance as the burnt connection, and if they are not made wholly of lead they soon become corroded.

62. The Electrolyte.—As already stated, the electrolyte consists of a mixture of sulphuric acid and water. There is a difference of opinion as to what the strength of the mixture should be, and makers of batteries send instructions with their cells as to the strength that they consider essential to secure the best results with their particular make of cell. The proper strength of the electrolyte is determined by means of a hydrometer.

Fig. 51 shows a storage-battery hydrometer. It consists of a sealed tube, or stem, provided with a bulb that is partially filled with shot or mercury. If placed in water, such a hydrometer will sink; but if acid is added, the solution becomes heavier, or more dense, and the hydrometer will float until its stem projects vertically out of the mixture. When the specified mark on the stem comes even with the surface, it shows that the proper density of mixture has been attained. The electrolyte in the cells should be tested from time to time to see that the density is correct. If it is found too high, some of the solution should be drawn off and more water added. The electrolyte will evaporate to some extent, and this loss should be made good by the addition of water. The density increases to some extent as the cell becomes charged. The usual density of the solution should be about 1.2, or 1,200 on some hydrometer

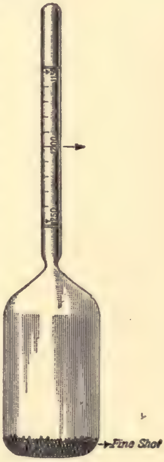


FIG. 51.

scales, though some manufacturers use a higher density than this. This means that the weight of the solution, per unit volume, is 1.2 times that of water. With ordinary commercial acid this density requires about 3 parts, by volume, of water to 1 part of acid.

When mixing the electrolyte, pure acid and water should be used; the water used for the electrolyte should be distilled. The acid evaporates very little, though some of it may be lost in the form of spray thrown off. The evaporation is nearly all water; hence, it is not often necessary to add acid to the cells. The electrolyte should be cold before it is placed in the cells, and they should be charged as soon as it is placed in them. They should not, at the most, be allowed to stand for more than 2 hours before being charged. It may be well to mention here that when sulphuric acid is to be mixed with water, *the acid should be poured slowly into the water.* If the water is poured into the acid, the sudden evolution of heat is apt to throw the mixture into the operator's face. The satisfactory operation of a battery depends to a great extent on the correct strength of the electrolyte, hence it should be carefully watched. The cells should be kept filled so that the electrolyte will always be slightly over the tops of the plates.

63. Charging.—Fig. 52 shows about the simplest possible arrangement of connections for charging a storage battery, all appliances that are not absolutely necessary having been left out in order to avoid confusion. *A* is a dynamo, usually either of the shunt-wound or compound-wound variety; *f* is the rheostat in its shunt field, by means of which the voltage of the machine may be varied through a considerable range; *V* is a voltmeter connected to the voltmeter switch *S*, which is so arranged that the voltmeter may be connected to either the battery *C* or the dynamo *A*; *E* is a double-pole knife switch, by means of which the battery may be thrown in connection with the dynamo; *F* is an ammeter that shows the amount of the charging current. The ammeters used with storage batteries are often made

with their zero point in the middle of the scale. When the battery is charging, the needle is deflected to one side of the zero mark; when discharging, it is deflected to the other side, thus showing at a glance whether the cells are charging or discharging. It should be noted that the + side of the dynamo is connected to the + side of the battery

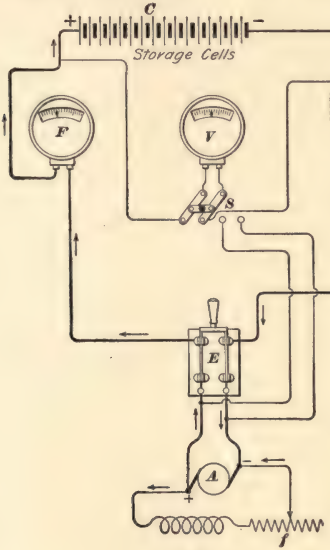


FIG. 52.

when the switch is thrown in, the direction of the charging current being indicated by the arrows. In this case, we have assumed that the number of cells to be charged is sufficiently great to take up the voltage of the dynamo; if this were not the case, a resistance would have to be inserted in series with the battery, as previously explained.

64. Having made sure that the connections are all right, see that switch E is open and get the dynamo up to speed.

Then measure the voltage of the cells and adjust the field rheostat of the dynamo until the voltage of the latter is from 5 to 10 per cent. higher than that of the cells. Throw in the main switch and adjust the rheostat until the ammeter indicates the charging current called for by the makers of the cells. When the cells are charged for the first time, some makers recommend that they be charged at about one-third the usual rate for the first 3 hours. As the cells become charged, the voltage of the dynamo must be increased, by cutting out field resistance, in order to maintain the charging current. Charging at a rate higher than that allowed by the makers is almost sure to injure the cells in time. Charging at a low rate is, in some cases, beneficial when the cells are not in good condition; but if the cells are all right, slow charging is of no particular benefit and consumes time. By keeping track of the length of time the battery has been charging, the attendant can usually tell when the cells are fully charged. If the cells happen to be overcharged a little, it does them no harm, but it results in a waste of current. Other things besides the number of ampere-hours supplied point out the fact that the cells are fully charged; the positive plates become a dark-chocolate color, almost black; the voltage across each cell rises to about 2.5 volts. Another indication of a fully charged cell is "gassing." When the cell is fully charged, oxygen and hydrogen are given off freely because they are no longer able to combine chemically with the plates, and after a cell has been gassing 10 or 15 minutes it may be assumed that it is fully charged. These gases fill the electrolyte with minute bubbles and make it milky in appearance. The bubbles rise to the surface and make the electrolyte appear as if it were boiling.

65. Simple Switchboard for Storage Battery.—The outfit shown in Fig. 52 is sufficient where a battery is simply to be charged and where a fairly close watch can be kept on it while the charging process is going on. Generally, however, the connections must be arranged so that the cells

may be either charged from the dynamo or allowed to discharge into the line. It is also necessary to have fuses or an automatic circuit-breaker of some kind to protect the battery against overloads. An *underload switch* is, also, connected between the cells and the dynamo, as indicated by the dotted outline *K*, Fig. 52. The duty of this switch is to prevent the cells from discharging into the dynamo and running it as a motor. It is, usually, an automatic switch controlled by an electromagnet connected in series between the dynamo and the battery. If for any reason the current drops to a very low value, the electromagnet releases its armature, thus opening the switch and disconnecting the cells from the machine.

66. Automatic Overload-and-Underload Switch.—Fig. 53 shows a special automatic switch designed to protect the dynamo from any backward rush of current and, also, to protect the battery from overloads. Two coils *a* and *b* are connected in series between the battery and dynamo, as indicated at *K*, Fig. 52. If the current becomes excessive, coil *b* pulls up a core that releases a trip and causes the arm to fly out, thus breaking the circuit at *d*, *d*. When the battery is charging, coil *a* holds its armature, but if the current becomes very small, as it must do before it begins to reverse and flow back from the batteries, the armature is released, which action releases the catch and allows *c* to fly out. The instrument is, therefore, a protection against both underloads and overloads.

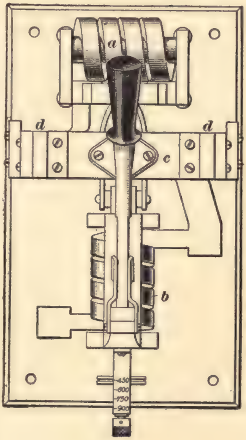


FIG. 53.

For example, a battery might be charging and the speed of the dynamo might drop or the belt fly off. In either

case, the voltage of the dynamo would drop and the charging current fall to zero. If the circuit were not opened, a current would flow from the battery through the dynamo and run it as a motor. Another instance in which damage might result if an underload switch were not used is in case the field circuit of the dynamo should happen to become

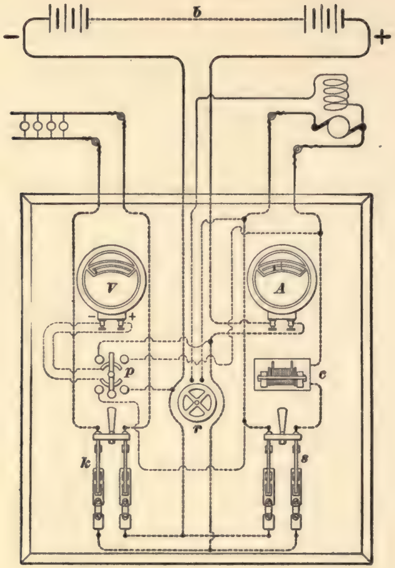


FIG. 54.

broken. This would reduce the E. M. F. of the dynamo to zero and a large rush of current could take place through the armature, because the cells would be unable to excite the field so as to enable the machine to generate any counter E. M. F. as a motor. In the case of a compound-wound dynamo, a backward rush of current might result in a

reversal of the dynamo field. In the case of a simple shunt dynamo, the current flows around the shunt in the same direction no matter whether the dynamo is charging the battery or whether the battery is forcing current back through the dynamo.

67. Fig. 54 shows a simple switchboard suitable for a small plant where a battery is used in conjunction with a dynamo for lighting or other purposes; *k* and *s* are two double-pole knife switches provided with fuses. The switch *k* controls the lighting circuit and switch *s* is connected to the dynamo *d* through the underload circuit-breaker *c*. The ammeter *A* is connected in series with the battery *b* and indicates the charging or discharging current. *V* is a voltmeter connected to a switch *p*, by means of which *V* may be connected across either the dynamo or the battery; *r* is the handle of the field rheostat that is connected in series with the shunt field of the dynamo. The rheostat is located behind the board. When the battery is being charged, the switch *k* is open and the switch *s* closed. When the battery alone is furnishing current to the line, *s* is open and *k* closed. If it is desired to have both battery and dynamo furnish current to the line, both switches are closed.

68. Discharging.—When a battery has been fully charged, it will retain its charge for a considerable length of time without serious leakage. The amount of leakage will depend on how well the cells are insulated. Except where the cells are used for portable purposes, they are usually discharged within a few hours after they are charged; in fact, in most railway or power stations the charging and discharging go on intermittently, charging occurring on the line when the load is light and discharging when it is heavy. The maximum discharge current is usually about the same as the charging current, though sometimes it is allowed to run slightly higher without damage. The maximum discharge current that may be taken from a cell depends largely on its construction and is usually specified by the makers. Heavy discharge currents are liable to heat the

cells and break up the plates by causing pieces of the active material to fall off. It is very bad practice to allow an accumulator to become completely discharged, as it is almost sure to give rise to a trouble called **sulphating,** and this, in turn, is liable to cause buckling of plates. It is always well to leave about one-quarter of the charge in the cells and never to discharge them to such an extent that the voltage per cell drops below 1.9 or 1.8 volts.

69. Sulphating.—This is one of the things that gives considerable trouble in connection with storage cells and which, if allowed to go too far, may render them almost useless. It has been stated that lead sulphate $PbSO_4$ is formed when the cells are charged or discharged. The formation of this sulphate is necessary in connection with the operation of the cell and it does no harm whatever. There is, however, another lead sulphate Pb_2SO_5, and it is this one that is generally credited with causing the trouble known as sulphating. This sulphate forms a white coating on the plates and generally accumulates more or less irregularly in patches. The white insoluble sulphate scale is very hard to get rid of and it prevents any action upon the portion of the plate that it covers. Because of this fact, it is responsible for a large portion of the buckled or bent plates that are sometimes found in cells. The patches of sulphate allow the plate to be acted upon in spots only and, as the active material expands and contracts when the chemical changes take place, the uneven expansion and contraction are liable to buckle the plate or cause the active material to fall off. As already stated, overdischarging is very liable to cause sulphating. It may also be caused by using too strong an electrolyte; i. e., an electrolyte having too large a percentage of acid in it. Also, if the cells are left standing for a long time without being charged, their charge may leak off and sulphating set in. If the sulphating has not gone far, the plates may be taken out and the white scale removed by scraping carefully. After this has been done, the cells should be charged at a low rate for a long time.

The positive plate generally gives the most trouble in storage batteries, hence this plate should be carefully watched for any signs of sulphating, buckling, or falling off of active material. If cells are to be left for a considerable length of time without being used, they should first be fully charged, the electrolyte drawn off, and the cells filled with clear water. They should then be allowed to discharge at their normal rate, which they will do for a short time only. After the water has stood in the cells for about 36 hours, it may be drawn off and the cells will remain in good condition until they are again put into commission.

70. General Remarks.—A storage battery, to give good service, must, like everything else, be kept in good condition. This means constant inspection of the plates and the condition of the electrolyte. The cells must be watched to see that none of them become short-circuited by particles becoming lodged between the plates or by material accumulating in the bottom of the cells. Cells should not be charged or discharged at an excessive rate for any length of time, though many of the batteries now manufactured will deliver heavy currents for short intervals without perceptible damage. Plates of the Planté type, i. e., with formed material, will, it is claimed, stand heavy charges and discharges better than those of the Faure, or pasted, type, which is a feature of considerable value in connection with automobile or other portable batteries. If plates become slightly buckled, they may be straightened by being pressed between boards—they should not be pounded. Battery rooms should be exceptionally well ventilated because of the fine acid spray that is formed when the cells are in operation. The bubbles of gas bursting at the surface of the acid throw off a very fine spray of acid that is extremely irritating. Different methods have been tried to keep this spray from being thrown off, such as pouring a layer of oil on top of the electrolyte or pouring melted paraffine on the surface. In the latter case, the paraffine hardens and seals the cell. A small hole about $\frac{3}{4}$ inch in diameter, or two or three of

such holes for a large cell, must be left to allow the gas to work its way out and also to permit the insertion of the hydrometer. The best method, however, of doing away with the trouble is to provide thorough ventilation.

REGULATION OF STORAGE BATTERIES.

71. Storage batteries in connection with large central stations are used in a number of different ways that will be taken up more in detail in connection with *Electric Lighting* and *Electric Railways.* In electric-lighting work, they are usually charged during the day and used to help out the dynamos at night, when the heavy load comes on. They are also used in some cases to carry the whole load during intervals when the demand is light. In railway work, they are generally left connected all the time the road is in operation; they are so arranged that they will become charged during the intervals when the load is light and will discharge when the load becomes heavy.

Since the voltage drops as the battery discharges, it is necessary, when they are used in connection with lighting work, to have some means of maintaining the pressure supplied to the line at a constant value. This is generally accomplished by having a few extra cells that may be switched into service by automatic switches as the voltage of the battery drops. In railway work, the regulation of the battery must be effected rapidly in order to make the battery charge or discharge with the rapid fluctuations in load peculiar to railway service. This is usually accomplished by means of a so-called *booster.*

The **booster** is a comparatively small dynamo of special design that is driven at a constant speed by a steam engine, or, what is more usual, by a direct-connected electric motor. The general action of a **differential booster** will be understood by referring to Fig. 55. The armature A of the booster is connected in series with the battery, so that whatever voltage may be generated in it will be combined

with that of the battery. In other words, varying the E. M. F. in *A* has practically the same effect as varying the E. M. F. of the battery by adding or cutting out cells. For example, the batteries will be charging whenever the voltage between the points *a*, *b* falls below that of the generator *G*, and they will discharge whenever it rises above that of *G*.

The field of the booster is provided with two windings, one of which consists of a few turns of heavy conductor and is connected in series with the line; the other winding is of fine wire and is connected in shunt across the battery as shown. A rheostat is provided in this shunt circuit so that

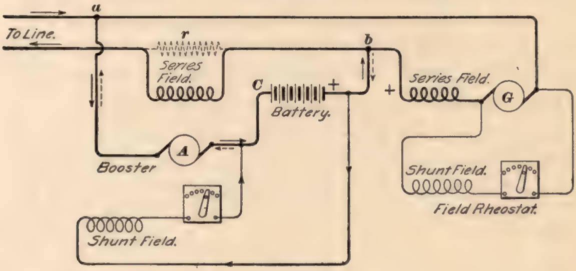


FIG. 55.

the field current may be adjusted. The effect of the series coil may be adjusted by means of a low-resistance shunt *r* connected across its terminals. The full-line arrows represent the course of the current when the cells are helping out the generator and the dotted arrows show the flow of current when the cells are charging. The shunt field of the booster supplies a practically constant magnetizing force because the current through the shunt remains almost the same, no matter whether the cells are charging or discharging, and the direction of the current in the shunt also remains the same. The series coils are so connected that the current passing out to the line circulates around them in a direction opposite to that in the shunt coils. The

windings are so adjusted that when the normal load is being delivered, the two coils balance each other and the booster armature generates no E. M. F. Suppose the current required on the line falls below the average or normal output. The shunt coil will then predominate, and the booster will generate an E. M. F. which is directed so that it is opposed to that of the cells (see direction of dotted arrows through booster), or in the same direction as that of the generator; hence it helps the generator to send current through the cells, as shown by the dotted arrows. When the line current becomes greater than normal, the series coil predominates, the booster E. M. F. is reversed and helps the battery to discharge and help out the dynamos. All that the booster does is simply to bring about a raising or lowering of the pressure between the points *a*, *b* so that the battery will charge or discharge at the proper time.

72. The preceding is intended merely to illustrate the general principle of booster regulation as used in connection with batteries. A number of patents have been taken out for different schemes of connections for this purpose, and the above is not, by any means, the only one that might be used.

73. Edison Storage Battery.—All that has been said in the foregoing relates to the ordinary lead-sulphuric acid storage cell, because this is the only type which has hitherto been used to any extent in practice. A new cell has recently been brought out by Edison which it is expected will be lighter and more durable than the older type. Whether this will prove to be the case remains to be seen, as the cell has not yet been used commercially on a large scale. The positive pole, or the plate at which current flows out when the cell is discharging, is a superoxide of nickel. The negative pole, or plate at which the current flows in when the cell is discharging, is iron. The electrolyte is a solution of caustic potash in water—about 20 per cent. of caustic potash is used. The plates are made of sheet steel and have openings in which fit small perforated flat steel boxes which

contain the active material. This cell give. an E. M. F. of 1.5 volts after being recently charged and an average voltage during discharge of 1.1 volts. It gives an output of 14 watt-hours per pound, which is equivalent to a weight of 53.3 pounds per horsepower-hour. It will be noticed that it is about two and one-half times as light as the lead cell for the same output, so that if it proves satisfactory in other respects, it will have a great advantage over the older type of accumulator.

COMBINED RUNNING OF DYNAMOS.

74. In preceding articles relating to the operation of dynamos in connection with power-transmission work, we have assumed, in nearly all cases, that each dynamo was operated by itself and that it fed into its own line or feeder. Where a station is equipped with a number of dynamos and circuits, it is often very desirable to have the machines arranged so that they may be operated together; generally in parallel, though in some cases in series. We will, therefore, take up some points relating to the combined operation of machines, both direct and alternating.

DYNAMOS IN SERIES.

DIRECT-CURRENT MACHINES.

75. Dynamos are not very often run in series. Perhaps the most common case is where they are run in pairs of two in series on the three-wire system. Of course, whenever dynamos are connected in series, their pressures are added in the same way that the voltage of two or more cells of battery is added when they are connected in series. The current output is not increased. The use of dynamos in series on the three-wire system has already been explained,

so that there will be no need to dwell on it further at this point. Sometimes when shunt-wound dynamos are operated in series, the shunt coils are connected in series also, so as to form a single shunt across both machines. In other cases, the shunt fields are connected so that the shunt of one machine is excited from the armature of the other. The object of using these different methods of connecting the shunt coils is to make the voltage divide equally between the machines, so that each will do its proper share of the work. Series-wound dynamos are sometimes operated in series, especially in connection with arc lighting. In this case, the connections are very simple, about the only precaution being to see that the positive pole of one machine is connected with the negative pole of the other, so that the pressures of the two machines will be added together instead of opposing each other. Generally speaking, series-wound, shunt-wound, or compound-wound machines may be run in series with very little difficulty; in the case of the last-named type, the compound coils must, of course, be connected in series in the line. In most cases, however, the demand is for a large current output rather than for a high voltage, hence plain series running is not very common, except, perhaps, on arc-light circuits, where a high voltage may be required for operating a large number of lamps in series.

ALTERNATORS.

76. Alternators cannot be run in series unless their armatures are rigidly connected by being mounted on the same shaft, so that the E. M. F.'s generated by the two machines will always preserve exactly the same relation with regard to each other. If the machines are driven separately, the E. M. F.'s may aid each other at one instant and oppose each other the next, thus making their operation unstable. For this reason alternators are very seldom operated in series.

DYNAMOS IN PARALLEL.

DIRECT-CURRENT MACHINES.

77. Dynamos, both direct and alternating, are much more frequently operated in parallel than in series. Nearly all modern electric-light, electric-railway, or electric-power-transmission plants are arranged so that the machines may be operated either singly or in parallel. When two dynamos *A* and *B* are connected to a line, as shown in Fig. 56, they

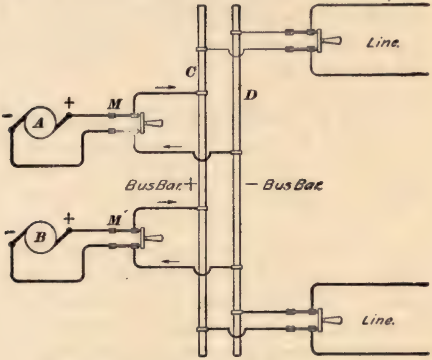


FIG. 56.

are in parallel. Each machine generates the same voltage, and the pressure between the lines is the same as if a single machine were used; i. e., the pressure between the lines is not increased by adding machines in multiple, but the current delivered to the line is increased because the line current is the sum of the currents delivered by each of the machines.

Each machine is connected through its main switch *M*, *M′* to the heavy conductors *C*, *D*, like terminals of each machine being connected to the same bar. As shown in the figure, the two positive terminals are connected to *C* and the two negative to *D*. Care must be taken to see that like terminals are always connected to the same bar. Each

machine, when so connected, delivers current to the main bars *C*, *D* and thence to the line. In fact, the whole arrangement is very similar to the steam piping between a battery of boilers and the engines. The dynamos correspond to the boilers and the bars *C*, *D* to the main steam pipe, or header, into which the various boilers feed; the lines running from *C*, *D* correspond to the steam pipes running to the engines. The bars *C*, *D* are called **bus-bars**; these bars carry all the current supplied by the machines, and it is delivered from them to the various lines. The bus-bars are generally heavy copper bars mounted on the back of the switchboard, and will be described more in detail in connection with the subjects of *Electric Lighting* and *Electric Railways*

It is not as easy a matter to operate machines in parallel as in series. It is evident that the voltage of each of the machines must be kept at the proper amount if the combination is to operate satisfactorily; for, suppose the E. M. F. of *B* should fall below that of *A*, then *A* would send current through *B* and run it as a motor, and *B* would thus be taking current from *A* instead of helping it feed into the line. There are a number of things that must be taken into account when machines are run in parallel that do not have to be considered when they are run separately. Compound-wound machines are run in parallel more than any other type in this country, though shunt machines are frequently run in this way also. Series machines are seldom run in parallel for reasons to be given later. We will, however, first consider the series machine briefly, because the compound-wound machine is a combination of the series- and shunt-wound machines and a glance at the operation of the series dynamo will help to make clear the performance of the compound dynamo.

SERIES-WOUND DYNAMOS IN PARALLEL.

78. Suppose we have two series-wound dynamos in parallel, as shown in Fig. 57, and assume that they are delivering current to a load of some kind and that each machine

supplies, say, one-half of the current. Now, if the E. M. F. of one of the machines A drops slightly, due to a slight variation in speed or any other cause, the amount of current delivered by A will decrease, and thus decrease the field excitation, because the current through the field coil is the same as the current delivered by A. This lowering of the field excitation of A will still further cut down its E. M. F. and matters will go from bad to worse until, in a very short time, A will be driven as a motor, unless the belt on the

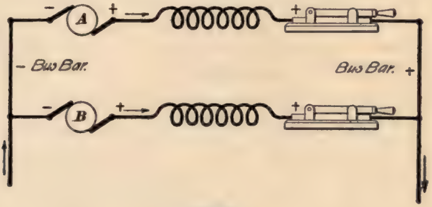


FIG. 57.

heavily loaded machine should slip and thus bring down its voltage. The trouble is made still worse by the fact that the extra load thrown on B will raise its E. M. F., because the field of B will be strengthened. Moreover, when A is run as a motor, its direction of rotation will be reversed; and this may result in considerable damage. It is thus seen that two series-wound machines connected in parallel, as shown in Fig. 57, will be very unstable in their action, and it is not practicable to so operate them.

79. Equalizing Connection.—The unstable condition just referred to can be remedied in a large measure by using an equalizing connection, or **equalizer,** as it is commonly called. This is shown in Fig. 58, where the wire $c\ d$ is the equalizer. The equalizer is a wire of low resistance connecting the points c, d where the series coils are attached to the brushes; e, f are the regular terminals of the machine; and the student should note carefully what points are connected by the equalizer. Now suppose that the machine B

delivers a greater current than A; part of this current will flow to the + line through the coil $d\,f$, but part of it will, also, take the path d–c–e through the field coil $c\ e$ of machine A. The result is that part of the current delivered

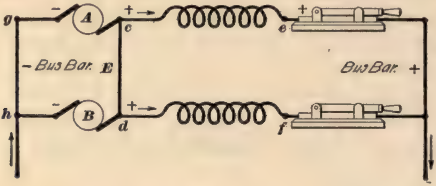


FIG. 58.

by B helps to keep up the field excitation of A, thus bringing up its voltage and equalizing the load between the machines. If A delivers the greater part of the load, due to a drop in the voltage of B, then part of the current flows through the path c–d–f and strengthens the field of B.

80. Even if the equalizer is used, there is another difficulty in the way of operating series machines in multiple that might not appear at first glance. Suppose that one series dynamo is carrying a load and that the load is increasing so as to make it necessary to put another machine in parallel with it to help it out. Now, in order to throw a dynamo in multiple with another dynamo that is already running under load, the dynamo that is to be thrown in must admit of having its voltage brought up to an amount equal to, or slightly greater, than that of the machine already in operation. If this were not done, the second machine would simply short-circuit the first as soon as a connection was made. Also, a series machine when run as a dynamo cannot generate any voltage unless it is allowed to deliver current, because the field coils are in series with the main circuit; so that in order to get the second machine up to voltage, we must either separately excite it in some way or provide a temporary load of some kind and then so arrange it that the machine can be thrown over on to the

main load. Either of these schemes will introduce complications. It is thus seen that the series dynamo is not at all well adapted for parallel running. The above points will, however, be of assistance in understanding the action of the compound-wound dynamo.

SHUNT DYNAMOS IN PARALLEL.

81. Shunt dynamos will operate very well in parallel and have been largely used in this way. They have two properties that make their parallel operation a comparatively easy matter. In the first place, they are capable of exciting their own field no matter whether they are delivering current to the main circuit or not. In the second place, their voltage drops slightly with an increase in the load, and this tends to make their parallel operation stable, as will be shown later. Suppose that we have two shunt machines arranged as shown in Fig. 59; *A* and *B* are the armatures of the two shunt machines, *S*, *S'* are the shunt field windings, and *r*, *r'* the adjustable field rheostats. *L*, *L'* are switches in the field circuit and *M*, *M'* main switches connecting the machines to the line. We will suppose that machine *A* is in operation, as indicated by the closed position of switches *L* and *M*. If now we wish to throw machine *B* into multiple, it is run up to speed and the switch *L'* closed; *B* will at once begin

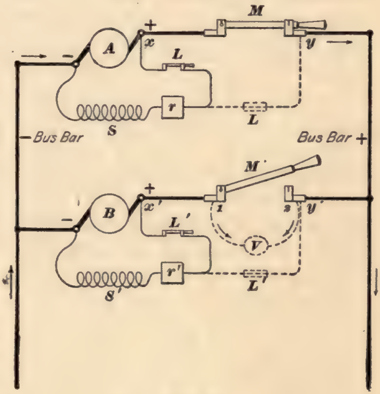


FIG. 59.

to pick up its field and run up to voltage. If the two machines are generating the same voltage and if their polarity is the same, as it should be, a voltmeter connected to blocks *1*, *2* will give no deflection, because the tendency of the machine *A* to send current through the voltmeter will be opposed by *B*. This state of affairs can be brought about by adjusting the rheostat r' until the voltmeter indicates that the voltages of the machines are equal. After this has been done, the switch M' may be closed and the field excitation of *B* again adjusted until the proper share of the load is carried. It is thus seen that there is no particular difficulty in throwing one shunt machine in parallel with another, because it can easily be brought up to the desired voltage, since the field circuit is independent of the main circuit. In practice, it is generally found better to have the voltage of *B* about 1 or 2 per cent. higher than that of *A* when the machine is thrown in.

Sometimes, when shunt machines are arranged for parallel operation, the field is connected across the mains instead of across the armature of each machine. When this is the case, the field connection is made as indicated by the dotted lines $r\,y$, $r'\,y'$, instead of being connected as shown by the full lines $r\,x$, $r'\,x'$. The effect of this is that the switch *M* must be closed before *A* will pick up, assuming that *B* is not in operation. If *A* is running and *B* is to be thrown in, then the switch L' is closed and *B*'s field is at once excited from the mains, so that *B* comes up to voltage almost immediately; after the voltage has been adjusted, switch M' may be thrown in as before. The reversal of the shunt-field connections on a dynamo that is to run in parallel with another dynamo is apt to give rise to trouble. If the field is connected, as shown by the full lines Fig. 59, so that the machine must supply its own field current before the main switch can be closed, no trouble is liable to arise; because with the wrong field connection, the dynamo cannot generate and the dynamo tender or switchboard attendant will notice that the machine does not pick up and will naturally look for the trouble. If, however, the field is connected in

beyond the main switch or across the station mains, as shown by the dotted lines, the machine becomes separately excited from the other dynamos that happen to be in service. It therefore generates an E. M. F. that is in just the opposite direction that it should be, and when the machines are thrown together, a rush of current takes place through the machine with the reversed field because its E. M. F. is in the wrong direction to keep out the current from the other machines. The result is, therefore, equivalent to a bad short circuit. Reversal of the shunt-field connection is not a common occurrence, but it has been known to happen where it has been necessary to disconnect the connections for purposes of repair or in order to move the dynamo.

82. We will suppose that the two shunt machines, Fig. 59, are running properly in multiple and will now see whether their operation will be stable or not. It has already been said that one property of the shunt dynamo is its tendency to drop its voltage as the current output increases. This fact is due principally to the drop in the armature and the armature reaction, as explained elsewhere. Now suppose that the voltage of *A* should drop slightly on account of a drop in speed or from any other cause. The tendency will be to throw the bulk of the load on *B*, with the result that *B*'s voltage will also drop on account of the above-mentioned property of the shunt-wound dynamo. The dropping of *B*'s voltage will relieve it of part of its load and will make it divide with *A*. It is thus seen that there is an automatic tendency for the load to equalize. Again, suppose that each machine is carrying a certain load and that the load on the line is suddenly increased, and that machine *B* takes more than its share of the current; the large current delivered by *B* will cause its E. M. F. to drop to more nearly that of *A*, and the load will thus be equalized. If the voltage of one machine should for any reason become so low that the other machine runs it as a motor, no harm is liable to result, because the direction of rotation of the machine as a motor will be the same as it is when being

driven by the engine as a dynamo. As far as parallel running goes, the shunt-wound dynamo is satisfactory, but it has been replaced by the compound-wound machine, because the latter will maintain the line voltage with an increase of load; whereas, with shunt-wound machines, the line voltage will fall off, unless the switchboard attendant cuts out some field resistance.

COMPOUND-WOUND MACHINES IN PARALLEL.

83. Since the compound-wound machine is a combination of the series and shunt machines, one would naturally infer that the arrangement for parallel running would be a combination of the two preceding ones. Fig. 60 shows the

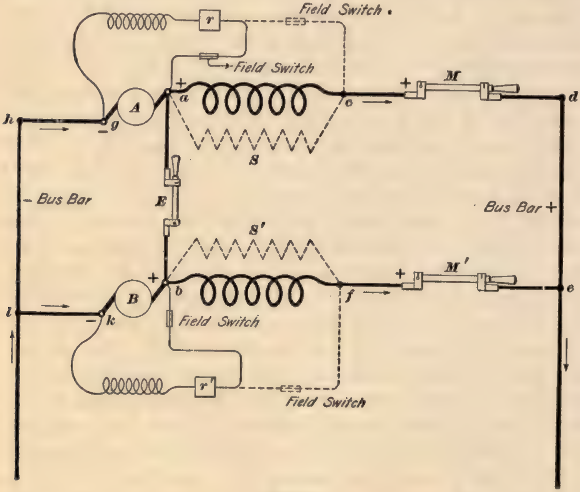


FIG. 60.

connections in their simplest possible form; we have two machines *A* and *B* of equal size and the equalizer *E* running directly between them; *c* and *f* are the + terminals of

the machine, while $c\,d$ and $f\,e$ represent the leads, or cables, running to the switchboard; $g\,h$ and $k\,l$ are the negative leads running to the negative bus-bar $h\,l$. There would be, in practice, a main switch in each of these negative leads, but as they are not essential for the present purpose they have been omitted, so as to make the figure as simple as possible. As shown by the full lines in Fig. 60, the shunt windings of the machines are connected in what is known as **short shunt**; i. e., the shunt field is connected across the brushes. Sometimes the shunt field is connected in **long shunt** across the terminals of the machine, as indicated by the dotted lines $r\,c$ and $r'\,f$. It makes very little difference as to the performance of the machine which connection is used.

Most compound-wound machines are provided with low-resistance shunts S, S' across their series coils in order that the degree of compounding may be adjusted. When machines are operated in parallel, these shunts should be adjusted so that the machines, when running separately, will give the same degree of compounding, which means, in the present case, that when each machine is delivering the same current, the voltage generated will be the same, because we are now assuming that A and B are of equal size. Another condition that must be fulfilled is that the resistance between the points a and d must be the same as between b and e. Since we are, for the present, assuming that the machines are of the same size and make, the resistance of their series coils $a\,c$ and $b\,f$ will be almost exactly the same. The resistance of the switchboard leads $c\,d$ and $f\,e$ must be the same, i. e., of the same length and cross-section; the resistance of the equalizer E should be as low as possible, and it should never be more than the leads $c\,d$ or $f\,e$.

84. We will now examine the action of the machines under a varying load. In the first place, if the resistance between $a\,d$ is equal to that between $b\,e$ and the machines are delivering equal currents, then the drop through $a\,d$ will

equal the drop through *b e* and points *a* and *b* will be at the same potential. Since current can only flow between points at different potentials, there will be no current in *E* under such circumstances. Suppose, however, that *A* delivers a greater current than *B*; then the drop in *a d* will exceed that in *b e* and current will flow through the path *a–E–b–f–M′–e* and thus build up the voltage of machine *B* and equalize the load. If *B* delivers more current than *A*, the drop in *b e* exceeds that in *a d* and current flows through the path *b–E–a–c–M–d*, builds up the voltage of *A*, and makes *A* take its share of the load.

85. In Fig. 60, the equalizer *E* is shown as connecting the positive brushes. This is usually the case in practice, though it would work just as well if both *a* and *b* were negative brushes and *c*, *f* the negative terminals of the machines.

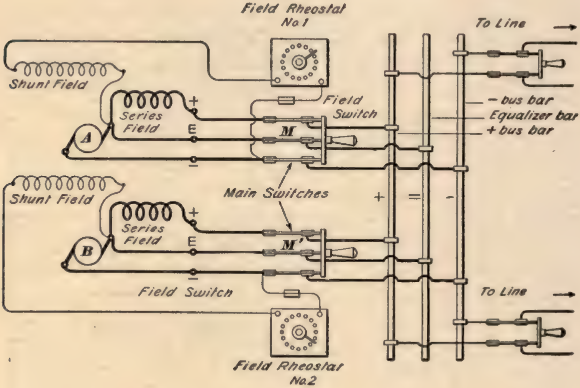


FIG. 61.

The only thing that must be looked out for is to see that the equalizer connects the brushes to which the series coils are attached, and also to see that these brushes are of the same polarity. In some cases, the equalizer wire is run directly

between the machines, as shown, but often a third wire is run from points *a* and *b* to the switchboard and there connected to an equalizer bar, as shown in Fig. 61. This represents a very common arrangement, triple-pole switches being used; the two outside blades for the + and − leads and the middle blade for the equalizer. There is a difference of opinion as to whether it is better to run the equalizer to the switchboard or run it directly between the

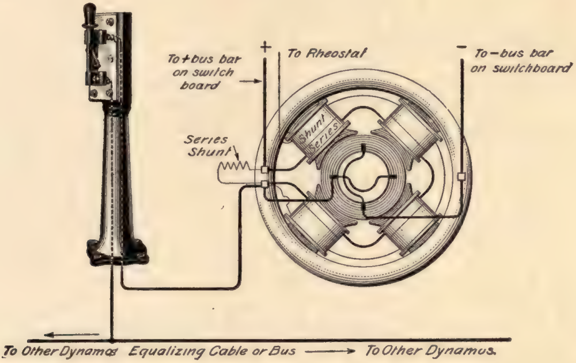


FIG. 62.

machines, as in Fig. 60. The most recent practice tends towards running it directly and placing the equalizer switch near the machine. This undoubtedly tends to make the connections shorter and thus leads to better regulation. In such cases, the equalizer switch is usually mounted on a pedestal near the machine, as shown in Fig. 62.

86. So far, in all that has been said, the machines were supposed to be alike in size and general design. Under such circumstances, there is generally no great difficulty in getting compound-wound machines to operate properly in parallel. Trouble is often experienced, however, when it comes to operating machines of different construction and size.

Some field magnets will respond to changes in field excitation much more quickly than others, and other differences in design may have considerable effect on the performance of the machines when they are run in parallel. When running two machines of different size in parallel, the problem is to get the load to divide between them in proportion to their size. For example, suppose we have a large machine A connected in parallel with a smaller machine B, as shown in Fig. 63. Each machine is supposed to be

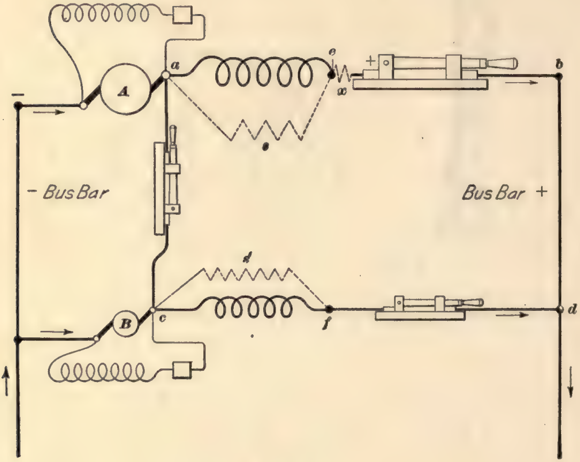


FIG. 63.

adjusted so that it gives the same degree of compounding when operated by itself. Also, when each machine is delivering its proper share of the load, the drop between $a\ b$ must equal the drop between $c\ d$. For example, if C is the full-load current of A, R the resistance between a and b, C' the full-load current of B, and R' the resistance between c and d, then $C \times R$ must equal $C' \times R'$. Now, the resistance of the series coils cannot very well be altered in order

to bring about the required condition of affairs, so that the only thing to do is to insert resistance of some kind in the leads *e b* or *f d* until the above drops become equal. This resistance will, of course, be very small and may be made up of a short piece of heavy German-silver strip or even an extra amount of cable in one of the leads. In the figure, this small additional resistance is indicated at *x*, though it may be necessary to insert it in the main lead of machine *B*. The resistance must be inserted in series with the machine giving the least drop between the points mentioned above. Many times the attempt is made to bring about the adjustment by changing the shunts *s s'*, but such attempts are useless, because just as soon as the machines are put in parallel, *s* and *s'* are also in parallel and are practically equivalent to one large shunt across the fields of both machines. The consequence is that any change in the shunts affects both machines. The adjustment must, therefore, be made in the main lead between the series coil and the bus-bar, and any resistance so inserted must have the same carrying capacity as the series coils. A change in the shunt across the series coils will change the compounding of the machines as a whole, but it will not better their condition as regards the correct division of the load.

87. The above are some of the main features connected with the running of compound-wound machines in multiple. In street-railway work, the load fluctuates through wide ranges and with great rapidity, and the proper running in multiple there represents more difficulties than in any other line of work. For the present, all that we wish to call attention to are the important points connected with parallel running under normal conditions.

88. Compound Machines in Multiple With Shunt Machines.—It is not practicable to run a compound-wound machine in multiple with a shunt machine. If, for any reason, the compound-wound machine takes a little more than its share of the load, the strengthening of its series coils makes it still further overload itself, with the result

that the field rheostat of the shunt machine calls for constant attention. The only way to run this combination satisfactorily is either to cut out the series coils of the compound-wound machine, thereby making both plain shunt machines, or else to provide the shunt machine with compound coils.

ALTERNATORS.

89. Alternators may be operated in parallel, although they are, as a rule, more troublesome than direct-current machines. This is especially the case if they are very different in size and design. For example, alternators with the old-style, smooth-core armatures are hard to run in parallel with modern machines having toothed armatures. In fact, in many of the older lighting stations special precautions were taken at the switchboard to see that two alternators should never be thrown in parallel. In modern plants, however, parallel running is quite common, and if proper care is taken, the machines may be thrown together without danger.

90. Alternators are operated in parallel in much the same way as direct-current machines, so far as connections are concerned; i. e., they are usually connected to bus-bars through the intervening main switches. If the alternators are compound-wound, an equalizing connection should be used; but very many of these machines are operated with a separately excited field only and no equalizing connection is necessary, the whole scheme of connection corresponding more nearly to the running of shunt-wound machines in parallel.

Suppose that we have two single-phase alternators A and B connected in parallel. In order that the machines may operate properly and each take its proper share of the load, it is, of course, necessary to have their voltages equal. There is another important condition that must also be fulfilled; the machines must be in **synchronism.** By this is meant that

the E. M. F. of A must come to its maximum value at just the same instant as the E. M. F. of B, or in other words, the electromotive forces of the two machines must vary in unison or be in phase with each other. This means that both machines must run at exactly the same frequency, for if this were not the case, they would get out of step. Before two alternators are thrown in parallel, equality of frequency is the most important condition to be fulfilled. A slight difference in phase will cause an exchange of current between the machines, but they will pull each other into phase if the frequencies are equal.

91. Synchronizing.—The state of synchronism is usually ascertained by means of **synchronizing lamps** placed on the switchboard and connected as shown in Fig. 64. T, T'

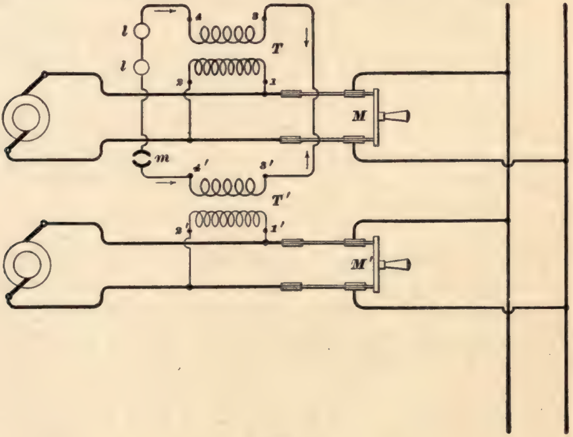


FIG. 64.

are two small transformers having their primary coils connected to the alternators, as shown. It should be noted that similar terminals *1*, *1'* are connected to similar sides of the machines. The secondaries are connected in series

through a pair of lamps *l*, *l* and a plug switch *m*. If the machines are exactly in phase, terminals *3* and *3'* will have the same polarity at the same instant and the polarity of *4* and *4'* will also be alike. But since like terminals are connected together, the two secondary voltages will just neutralize each other, as indicated by the arrows, and the lamps will not glow. If the machines were directly opposite in phase, the lamps would light up to full candlepower. It is evident that by reversing the connections of one of the transformers the state of synchronism will be indicated by the lamps being bright, but we will assume that they are connected as shown in the figure. When machine *B* is started and the plug is inserted at *m*, the lamps rapidly fluctuate in brightness; but as *B* comes more nearly in synchronism the fluctuations become much slower. When they have become as slow as one in 2 or 3 seconds, the main switch *M'* is thrown in at the middle of one of the beats when the lamps are dark. In many cases, the connections are so made that the lamps are bright when synchronism is attained, because there is a considerable interval during which the lamps are dark. Whether the state of synchronism will be indicated by light or dark lamps depends simply on whether the transformer secondaries are connected so as to assist or to oppose each other.

92. Synchronizing Two-Phase and Three-Phase Machines.—Fig. 64 shows the synchronizing arrangement for a single-phase machine. For a two-phase or three-phase machine the same arrangement may be used, only care must be taken to make sure that the transformers *T*, *T'* are connected to corresponding phases on each of the machines. This may be determined by using two pairs of transformers; i. e., one regular pair, as in Fig. 64, and a temporary pair on one of the other phases. For example, on a two-phase machine an arrangement similar to that shown in Fig. 64 should be made for each of the phases, and when the connections are right, each set of phase lamps will light or become dark, as the case may be, at the same time, showing

that both phases are ready for parallel operation. After it is known that the connections are all right, the temporary pair of transformers may be removed and only one pair used, as in Fig. 64.

93. Synchronizing Instruments.—A number of different styles of instruments have been designed to indicate when two alternators are in synchronism, and these are now used to a considerable extent in place of lamps. In some cases the lamps are replaced by a voltmeter. Another device consists of a pointer actuated by two small synchronous motors that are operated by the two machines to be synchronized. When the machines are in synchronism, these two small motors run at exactly the same speed. When they differ, the small motors run at different speeds, and the pointer on the dial indicates that the machines are out of synchronism.

94. If alternators are thrown in parallel before they are brought into phase, a heavy cross current will flow between them and damage may result. When they are running together, each alternator will hold the other in step and they will both run at such a speed as to give the same frequency; if they happen to have the same number of poles, the speeds will be exactly the same. Each alternator will deliver current in proportion to the power supplied it by the engine. The amount of current delivered by each alternator will also depend on its field excitation. If the field excitation of the machines is not maintained at the proper amount, there will be an idle current flowing between the alternators and the sum of the currents furnished by the machines will be considerably greater than the current delivered to the line. The field excitation should be such that the sum of the currents delivered by the individual machines will be as nearly as possible equal to the current delivered to the line. When running alternators in multiple, it is best to let one engine do most of the governing and have the second governor arranged so that it will act slowly and will let the first governor take care of the finer

adjustments in speed. When machines are belt-driven, great care must be taken to see that the pulleys are exactly the correct dimensions to give the speeds required for operating in synchronism; because if this is not the case, there will be considerable belt slippage and there will also be considerable cross current between the two machines. The running in multiple of alternators coupled direct to engines often presents difficulties on account of the rotary motion of the engines not being absolutely uniform. This is especially the case if the engines are provided with light flywheels or poor governors. It does not take much angular variation between the two engines to throw the machines out of synchronism and thus cause cross currents to seesaw between the alternators. In cases where it is proposed to operate direct-connected alternators in multiple or direct-connected machines in parallel with belted machines, full details should be furnished to the manufacturers, so that the engines and dynamos may be fitted to this class of work.

95. All cables running from the dynamos to the switchboard should have a cross-section of at least 1,000 circular mils per ampere. If two machines are run in parallel, the equalizing cable should have a cross-section of 1,500 circular mils per ampere of the full-load current of the machines to which it connects. Generally speaking, the lower the resistance of the equalizer cables the better will the machines operate. All main leads running from the machines to the switchboard should be of a first-class quality of rubber-covered cable, and where high-tension alternating-current machines are used, special precautions should be taken to secure high insulation of the wires and avoid crossings as much as possible.

ELECTRIC LIGHTING.

(PART 1.)

INTRODUCTORY.

1. The subject of electric lighting involves a consideration of the different methods used for carrying out artificial illumination by means of electrical energy. This means that not only must the actual means of converting the electrical energy into light be considered, but that the methods used for its generation and distribution must also be given due attention.

2. There are, in general, two methods in common use for producing light by means of electricity: (*a*) By means of incandescent lamps; and (*b*) by means of arc lamps.

Both of these methods are extensively used, the arc light being especially adapted for street lighting, although it is largely used for interior lighting as well. The principal field for incandescent lighting is interior illumination, but incandescent lamps are also used for street lighting, especially in places where the streets are thickly shaded by trees, or in cases where a fairly uniform distribution of light is desired.

3. In the incandescent electric lamp, light is produced by bringing a continuous conductor of high resistance to a very high temperature by passing a current through it. If a current is sent through a conductor, there will be a certain loss of energy in the conductor due to the resistance that the current encounters in flowing through it, and this loss reappears in the form of heat. In the incandescent lamp,

the construction of which will be described later, this heating effect is so intense that it raises the conductor to incandescence and so produces the desired illumination.

4. The illumination produced by the arc lamp is brought about in an entirely different way. In this lamp the current is made to pass between two carbon points that are held automatically a short distance apart. The points of these carbon rods become heated to an exceedingly high temperature and a very brilliant light is produced. The arc lamp was first publicly exhibited by Sir Humphry Davy in London in the year 1810, when he used a battery of 2,000 cells for its operation. Arc lamps did not come into commercial use until a much later period, because current could not be supplied cheaply enough by means of batteries, and the introduction of the light was not accomplished until the dynamo-electric machine had been developed sufficiently to insure the generation of electrical energy at reasonable cost. The arc lamp will be described in detail when this system of lighting is considered by itself. For the present, we will confine our attention to the methods of artificial illumination as carried out by the incandescent lamp.

5. Arc and incandescent lamps may be operated by means of either the alternating current or the direct current. Arc lamps have, in the past, been operated principally by direct current, but alternating current is now being largely used for this purpose. Incandescent lamps will operate quite as well with alternating as with direct current, provided the frequency is not too low. The heating effect in a conductor is independent of the direction in which the current flows; hence, an alternating current, which periodically reverses its direction of flow, will operate an incandescent lamp just as well as a direct current, which always flows in the same direction. The reversals of the current are so rapid that the conductor in the lamp does not have time to cool off perceptibly, and, hence, there is no flickering noticeable to the eye. If, however, a frequency below 30 cycles per second is used, the lamps are apt to

flicker, and if alternating current is to be used for incandescent lighting work, the frequency should not be below this value.

6. In taking up the subject of electric lighting, we will then have the four following divisions to consider:

1. Incandescent lighting by direct current.
2. Incandescent lighting by alternating current.
3. Arc lighting by direct current.
4. Arc lighting by alternating current.

These main divisions of the subject cover broadly the numerous systems in common use; they may be still further subdivided, but the various modifications will be taken up when each of the above divisions is considered by itself.

INCANDESCENT LIGHTING.

THE INCANDESCENT LAMP.

7. The **incandescent lamp** is naturally the first thing to be considered in connection with the subject of incandescent lighting, as it is by means of this lamp that the electric energy is made to furnish the required illumination. Fig. 1 shows a typical incandescent lamp with which everyone is familiar.

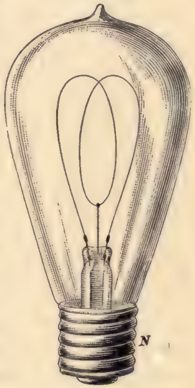


FIG. 1.

In order that the lighting service supplied from an incandescent plant shall be satisfactory, it is highly important to see that the lamps are efficient. If poor lamps are used, or if the lamps are burned beyond their useful life, poor service will result no matter how efficient the system may be in other respects. It is useless to install the best generating machinery available and then expect to give a good

service with old or cheap lamps that soon run down in candlepower. Central-station managers are coming to realize this point more than was once the case and are devoting more attention to the quality of the lamps that they buy; in fact, most progressive companies now provide means for testing their lamps.

CONSTRUCTION OF LAMPS.

8. Early Experiments.—It was not long after the invention of the arc lamp until inventors turned their attention to the production of electric light by heating continuous conductors to a high temperature by means of the current, instead of using the arc, because the early forms of arc lamps were not well suited to interior illumination. The first experiments were made with platinum or iridium wire. These wires were mounted in the open air and current sent through them, the current bringing the wire to a white heat and thus causing light to be given off. All these lamps proved failures because the wire very soon burned out. The temperature to which it had to be raised was very near the melting point of the metal, and if great care were not exercised the wire would fuse. In later experiments, the wire was enclosed in a glass globe from which the air was exhausted. This was a great step in advance, because it prevented the conductor from becoming oxidized and thus destroyed by the action of the air; it also prevented the wire cooling off so fast, and thus allowed the high temperature to be maintained by a much smaller current than would be required were the wire heated in the open air. Even when the platinum or iridium wire was enclosed in a globe from which the air had been exhausted, it was found that, although the lamps were very much improved, they were not suitable for commercial use. It became evident that some substance that would be cheaper and capable of standing a higher temperature would be necessary. Carbon was finally selected as the substance most suitable and is now universally used.

9. There has been considerable discussion as to who invented the incandescent lamp, and the probabilities are that its invention was not due to any one person. Edison tried a great many experiments to determine the best substance for the conductor, or **filament,** as it is usually called. The material that he finally selected was bamboo fiber, which was cut to the proper size and then carbonized. Maxim made lamps with filaments of carbonized paper. These lamps embodied all the essential parts contained in the modern lamp shown in Fig. 1, but lamps as now made are very much improved in efficiency and are decidedly cheaper. The work of Edison undoubtedly first placed the incandescent lamp on a commercial basis.

10. Filaments.—As mentioned before, bamboo was used at one time for the construction of lamp filaments. Fig. 2 shows the general shape of one of these early bamboo filaments. The ends *a*, *a* were enlarged so that the heating at the joint between the leading-in wires and the filament would be much less than that of the filament proper. Lamp

FIG. 2.

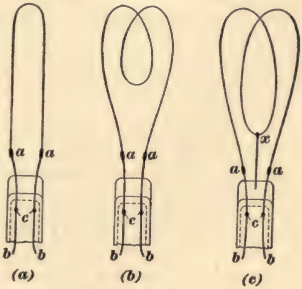


FIG. 3.

filaments as now made are usually in the forms shown in Fig. 3 (*a*), (*b*), and (*c*). (*a*) is the plain loop filament, (*b*) the spiral, and (*c*) the oval. In Fig. 3 (*c*), the filament is fastened at *x* to a small anchor wire fused into the glass, and is spoken of as an **anchored filament.** This is done to prevent violent vibrations of the filament, which would tend

to shorten the life of the lamp, and lamps of this type should be used in any place where they are subjected to vibration, as, for example, on street cars. Filaments have been made of carbonized silk or cotton, but the more common method of manufacture at present is by what is known as the squirting process. This process consists in squirting the material, usually cellulose or a mixture of carbonaceous materials, through dies. These threads are then cut to the proper length, wound on forms to hold them to the required shape, and carbonized. This process has been found to make more uniform and very much cheaper filaments than the older methods.

With the old process of making filaments, it was necessary to treat them to what is known as the flashing process. This was necessary because the old-style filaments were not uniform in cross-section, and when used in the lamps would glow more brightly in some spots than others and soon burn out. To overcome this, the filaments were placed in a hydrocarbon vapor and current sent through them until they were brought to a red heat. The parts that were small in cross-section would become hotter than the rest of the filament, and carbon in the form of graphite would be deposited on these parts, thus bringing up their cross-section and making the filament uniform. This process is not necessary with modern filaments in order to make them uniform, but it is continued, nevertheless, because it has been found that the layer of graphitic carbon so deposited makes the lamp have a considerably higher efficiency than it would otherwise have. The layer of graphitic carbon is a much poorer radiator of heat than the body of the filament, and thus allows the temperature necessary for the emission of light to be maintained with a less expenditure of energy than would the untreated filament. It is this layer of graphitic carbon that gives the filaments their familiar steel-like appearance.

11. The size of the filament depends altogether on the candlepower of the lamp and the voltage and current with which it is to be supplied. The lamp shown in Fig. 1 is one

of 16 candlepower, such as would ordinarily be used on a 110-volt circuit. Such a lamp would require about ½ ampere; hence, from Ohm's law, its resistance when hot must be in the neighborhood of 220 ohms. In order to get such a high resistance, the filament must be long and fine. Lamps designed for low voltage and large current would be provided with short, thick filaments. Fig. 4 shows a low-voltage lamp designed to take about 3½ amperes. In this case the filament is short and correspondingly thick. Lamps with thick filaments, like the one shown in Fig. 4, are not so efficient as those with long, fine filaments.

FIG. 4.

Fig. 3 shows the way in which the filaments are usually mounted. The filament is fastened to the platinum wires *a*, *a*, which are sealed into the glass and thus render the globe air-tight. The junction between the filament and the leading-in wire is effected by means of carbon paste; this paste also enlarges the cross-section of the joint, so that the heating is small compared with that which takes place in the filament itself, and the leading-in wires are, therefore, kept cool.

12. The Leading-In Wires.—These are made of platinum, because this metal has almost exactly the same coefficient of expansion as glass, and also because it does not oxidize. If the glass and platinum did not expand at the same rate when heated, cracks would form at the point where the wires are sealed into the glass. This would let in the air and the filament would soon burn out. A film of oxide on the leading-in wires would also tend to let air leak into the globe, and platinum does not oxidize. Only enough platinum is used to pass through the glass, as shown at *a*, *a*, Fig. 3. Connection is made to the base by means of small copper wires *b*, *b* fused to the platinum at *c*, *c*. In early lamps, the whole length of the leading-in wires was of

platinum, but this practice has been discontinued, owing to the high price of the metal. Substitutes for platinum for the leading-in wires have been brought out from time to time, but none of them have displaced it as yet.

13. The Bulb.—The style of bulb used to enclose the filament is familiar to almost everybody. Different shapes are in use, but by far the most common is the pear-shaped bulb shown in Fig. 1. The bulbs should not be made too small, because, as the lamp burns, the filament gradually undergoes disintegration and small particles of carbon are thrown off and deposited on the globe. This causes the well-known blackening of the lamp, and if the bulb is very small this blackening is aggravated, because the surface is smaller and the deposit, for that reason, more dense.

14. Exhaustion.—Fig. 5 shows a lamp after the stem carrying the filament and the leading-in wires have been sealed into the bottom. The lamp is now ready to be exhausted. In order to accomplish this, a small glass tube with a narrow neck at *a* is sealed into the top of the bulb. This tube is connected to an air pump, and while the air is being exhausted a current is sent through the filament. This current is gradually increased as the exhaustion progresses, and, by heating the filament, drives out any air that may have been absorbed by the carbon. The operator can tell by the performance of the lamp when the proper degree of exhaustion has been reached, and seals up the bulb by melting the glass tube at the neck *a*.

FIG. 5.

Numerous methods have been devised for the exhaustion of lamps. Ordinary mechanical air pumps, i. e., pumps that exhaust the air by the operation of a

plunger in conjunction with valves, are not capable of producing a sufficiently high degree of exhaustion. They are, however, used to exhaust the greater part of the air, and the final exhaustion is then accomplished either by means of a mercurial air pump or by the chemical method.

The principle of operation of the Sprengel mercurial air pump is shown by Fig. 6; *c d* is a glass tube with a **T** joint at *x*, from which a branch tube leads to the lamp. The lower end of the tube dips below the surface of the mercury in the vessel *B*. Mercury is allowed to run from *A* by opening the pinch-cock *c*, and in doing so draws the air out of the bulb by carrying down a stream of air bubbles until the air is completely exhausted. When the air has become exhausted, the mercury falls from the top to the bottom of the tube with a sharp click. This style of pump is capable of producing a high degree of exhaustion, but, unfortunately, it is rather slow in its action. The pump has been modified in various ways to adapt it to commercial work, but its action is briefly as outlined above.

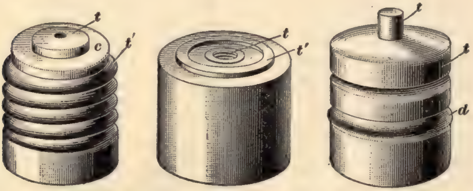
FIG. 6.

Another method of exhaustion, known as the chemical method, has recently come into use, and has rendered the

process of exhaustion much more rapid. In this process, the air is first exhausted to quite a high degree by mechanical pumps. A gas is then introduced, which combines with the remaining gases and renders them incapable of acting on the filament. The process is in the main kept secret; it produces a vacuum that gives as good results as that produced by a mercurial pump, and the process is much more rapid. The chemical that is often used is phosphorus, a small quantity of which is placed in the stem of the bulb and heated when the mechanical pumps have produced the proper degree of exhaustion.

15. Bases.—After the lamp has been exhausted, it is complete with the exception of the base N, Fig. 1, with which it must be provided in order that it may be readily attached to the socket. These bases are usually made of brass and porcelain, the lamp being held in them by a setting of plaster of Paris or cement.

In Fig. 5, the lower part of the lamp is made of such shape that the base will be held securely when the plaster of Paris is put in place. The rib b prevents the base from pulling off. The base must, of course, provide two terminals for



(a) (b) (c)

FIG. 7.

the leads from the filament, these terminals being arranged so that when the lamp is placed in the socket, contact will be made with two corresponding terminals. There are three different bases commonly used in America; these are

the *Edison;* the *Thomson-Houston*, or *T. H.*, as it is more commonly called; and the *Westinghouse*, or *Sawyer-Man.* These bases are shown in Fig. 7.

16. Fig. 7 (*a*) shows the **Edison base,** of which there are more in use than all the others put together. One end of the filament is attached to the outer shell *t'*, which is provided with a coarse screw thread. The other terminal is connected to the projecting center piece *t*, the two brass pieces being separated by means of a porcelain piece *c*. When the lamp is screwed into the socket, the screw shell makes one connection and the center piece the other. Fig. 8 shows a lamp screwed into an ordinary Edison key socket.

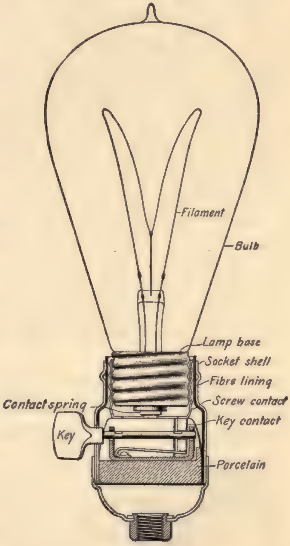


FIG. 8.

Fig. 7 (*b*) shows the **T. H. base,** so called because it was brought out by the Thomson-Houston Company. In this base, one terminal is connected to a center brass piece *t* in which a hole is drilled and tapped. The other terminal is connected to the brass ring *t'*. This base has the advantage that the outer shell, if one is used, is in no way connected to the circuit, and there is, therefore, less danger of receiving a shock by touching the lamp; it has been, and still is, used to a considerable extent, though it is gradually going out of use, as it is more expensive to make than the Edison base. It works loose in the socket a little more easily than the Edison base when the lamp is subjected to vibration. When placed in the socket, terminal *t*

screws on a projecting stud, thus making one connection; the other connection is made by the ring *t'* coming into contact with a corresponding ring or terminal in the socket. The later types of T. H. base are made of porcelain with a brass center piece and outside ring, as described above.

Fig. 7 (*c*) shows the **Westinghouse base,** or the Sawyer-Man base, as it is sometimes called, because it was originally brought out by The Sawyer-Man Company. This base is similar in some respects to the Edison, but the outer shell is not threaded; the lamp is pushed into the socket, the outer shell slipping into a split bushing that is provided with an annular groove. The rib *d* slips into this groove when the lamp is in position and prevents the lamp slipping out. The other connection is made by the projecting pin *t* coming into contact with a spring in the socket. This base has the fault that it sometimes allows the lamp to drop out of the socket if the split bushing does not grip the rib *d* properly. It also makes comparatively poor contacts, which become worse with use.

17. When incandescent lamps were first brought into use on a commercial scale, each different maker had his own style of lamp base, and the result was that over a dozen different types were in use. The number has, however, been gradually reduced until the three mentioned above probably include over 95 per cent. of all the bases in use in America. The chances are that in a few years the Edison base will have replaced the others, because, taking everything into consideration, it is the best base of the three. Even plants that are equipped with sockets of other makes are fitting them with adapters so that they may be able to use Edison base lamps. Fig. 9 shows an adapter for changing T. H. sockets to take lamps with the Edison base.

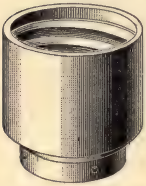


FIG. 9.

MEASUREMENTS AND LAMP CALCULATIONS.

LIGHT MEASUREMENTS.

18. Incandescent lamps are usually spoken of as giving a certain number of candlepower. For example, a lamp is spoken of as giving 16 candlepower when it produces an intensity of illumination equal to that produced by 16 standard candles.

19. The unit of brightness most commonly used is a spermaceti candle of standard dimensions. Standard candles are .9 inch in diameter at the base, .8 inch in diameter at the top, and 10 inches long; they burn 120 grains of spermaceti and wick combined per hour. Six candles weigh 1 pound. The candle is not a very satisfactory standard, as it is subject to considerable variation, and other standards have been brought out to replace the candle in practical work. Various kinds of gas and oil lamps have been used for this purpose, which, although less liable to fluctuations than the candle, have not yet superseded it.

The **Methven screen** is a convenient standard that has been used largely. This standard consists of an Argand gas burner that is provided with a screen that cuts off all the light from the flame except that of a small portion that is allowed to come through a thin-edged standard opening in the screen. The size of the opening is .233 inch wide and 1 inch long. The height of the flame is 3 inches and the screen is placed 1½ inches from the axis of the flame. It is evident that the light given by a standard of this kind will vary considerably with the quality of the gas used, and while it may not be reliable as an absolute standard, it makes a very good working standard after its candlepower is known by comparing it with a standard candle. A slit of the above size should emit about 2 candlepower.

One of the best light standards is the **amyl-acetate or Hefner unit.** This lamp consists of a small reservoir provided with a wick tube of standard size. The lamp burns

amyl acetate and the flame is adjusted until its tip is 40 millimeters above the top of the wick tube. This standard is very reliable and is subject to little variation. It has the disadvantage of giving a light of reddish tinge. The Hefner unit is not quite as large a unit of light as the English candle, the relation being 1 candle = 1.14 Hefner units.

For photometric tests connected with electric-light stations, neither the candle nor the amyl-acetate lamp is used as a working standard.

The general practice is to standardize either an incandescent lamp or an oil lamp by comparing it with the standard and then use the lamp so calibrated for the actual work. For example, an incandescent lamp might be carefully compared with a standard candle and its candlepower accurately determined for a given voltage. This lamp could then be used as a standard in measuring the candlepower of other lamps, provided its voltage were maintained at the correct value. A secondary standard of this kind is very much easier to work with and cheaper to operate than either a standard candle or amyl-acetate lamp. An oil lamp may also be calibrated in the same way and makes a satisfactory secondary standard for practical measurements when extreme accuracy is not required.

20. In order to determine the candlepower of an incandescent lamp, we must have some means of comparing the intensity of illumination produced by the lamp with that produced by the standard. An instrument for doing this is called a **photometer.**

21. Law of the Photometer.—Suppose that we have a candle placed at *A*, Fig. 10, and hold a screen *B* at a distance of, say, 2 feet from it. The screens are here shown bent so as to represent portions of spherical surfaces with *A* at the center.

Consider the portion of the screen *a b c d*. The intensity of illumination on the area *a b c d* will be a certain amount. Now, suppose the screen to be moved back to the position *C*, 4 feet from *A*. The total amount of light that fell on the

area *a b c d* will now be distributed over the area *a' b' c' d'*. The area *a' b' c' d'* is four times that of *a b c d*, because *A m* is twice *A f* and *m h* is twice *f g* or *b' c'* is twice *b c*. The total *quantity* of light falling on the two surfaces is the same, and since the area of *a' b' c' d'* is four times that of *a b c d*, it

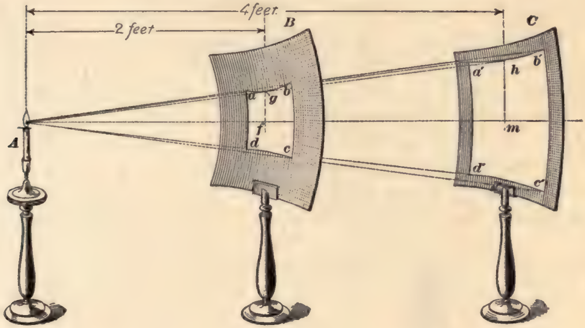


FIG. 10.

follows that the light per unit area or the *intensity* of illumination on *a' b' c' d'* is only one-quarter that on *a b c d*. In other words, doubling the distance of the screen from the source has cut down the intensity of illumination to one-fourth its former value. If the distance *A m* were three times as great as *A f*, the intensity of illumination would be one-ninth that on *a b c d*. This law may then be stated as follows:

The intensity of illumination produced by a source of light on any object varies inversely as the square of the distance of the object from the source.

The word inversely is used to signify that the *greater* the distance, the *less* is the illumination. This may be also expressed as follows: If x is the illumination produced and I is the brightness of the source of light, then

$$x = \frac{I}{d^2}. \qquad (1.)$$

This means, for example, that the illumination of the surface will be doubled if the candlepower of the source is doubled and that it will be one-quarter as great if the distance from the source is doubled.

22. Elementary Photometer.—Suppose, now, that we have two sources of light, such, for example, as a candle and an incandescent lamp, and that we wish to compare the brightness of these two sources. If the candle *A* and the lamp *B* are placed in a dark room, so that there will be no other light to interfere, and a screen *C* is placed between them, as shown in Fig. 11, one side of the screen will be illuminated by the candle and the other by the lamp. If the candle and lamp were exactly of the same brightness, it is evident that the two sides of the screen would be equally

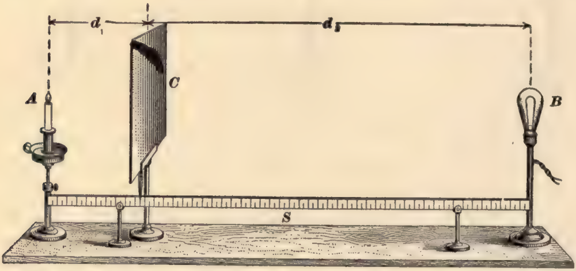


FIG. 11.

illuminated when placed midway between them. If the screen is mounted so that it can be slid along between the lights, a point can always be found where the screen will be equally illuminated on both sides. In the present case, the screen would have to be moved nearer the candle than the lamp, because the candle is not as bright as the lamp. Suppose that the screen has been adjusted so that the illumination is equal on each side, and that the distances d_1 and d_2 have been read off by means of the scale S, d_1 being the distance from the screen to the standard candle and d_2

the distance from the screen to the light that is being measured.

Let x_1 be the degree of illumination produced on one side and x_2 that on the other, and I_1 and I_2 the candlepowers of the standard and the light being measured, respectively. Then from formula **1**, we have

$$x_1 = \frac{I_1}{d_1^2} \text{ and } x_2 = \frac{I_2}{d_2^2};$$

but since the illuminations on the two sides are equal, we must have

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}.$$

Now, the candlepower I_1 of the standard is supposed to be known, and since the distances are also known, the candlepower I_2 of the lamp being measured can at once be calculated. For this purpose, it is more convenient to have the last equation in the form

$$I_2 = I_1 \frac{d_2^2}{d_1^2}. \qquad (2.)$$

23. The arrangement shown in Fig. 11 is a simple form of photometer, and formula **2** expresses the relation between the candlepower of the standard and that of the lamp being measured. This may be written in the form of a rule, as follows:

Rule.—*The candlepower of the lamp being tested on a photometer is found by multiplying the candlepower of the standard by the quotient obtained by dividing the square of the distance of the lamp from the screen by the square of the distance of the standard from the screen.*

EXAMPLE.—Suppose, in Fig. 11, that A is a standard candle giving 1 candlepower and that B is an incandescent lamp. The screen is moved until a point is found where the two sides are equally illuminated. The reading on the scale then shows that the distance from the standard is 20 inches. The total distance between the lamps is 100 inches. What is the candlepower of B?

SOLUTION.—If the total length of the photometer is 100 inches, the distance from the lamp to the screen must be $100 - 20 = 80$ inches. The candlepower of the standard is 1; hence, substituting in formula **2**,

$$I_x = 1 \times \frac{80^2}{20^2} = 16 \text{ c. p.} \quad \text{Ans.}$$

24. The Bunsen Photometer.—The Bunsen photometer has been more largely used than any other. It is very simple and is capable of giving good results if used properly. The arrangement of the different parts is essentially the same as that shown in Fig. 11, but the distinguishing feature of this photometer lies in the style of screen

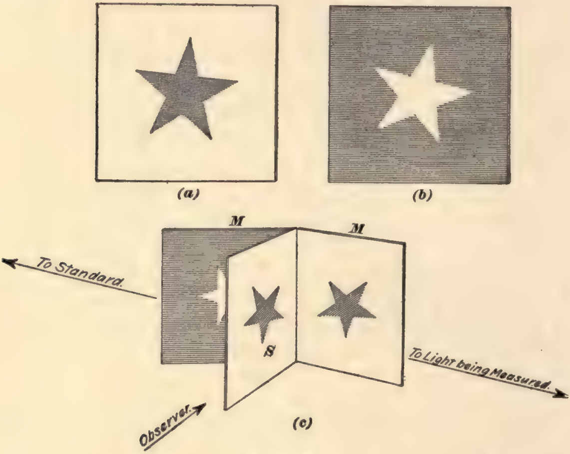


FIG. 12.

used. It would be a difficult matter to tell when a simple screen like that shown in Fig. 11 was illuminated equally on both sides, and to overcome this difficulty Prof. Bunsen devised the screen shown in Fig. 12. The screen is made by taking a piece of good quality of white paper and making a grease spot in its center, as indicated by the star in Fig. 12. If such a screen be held so that the front side is more strongly

illuminated than the back side, the grease spot will appear dark on the white ground of the paper, as shown in (*a*). If, however, the screen be more brightly illuminated on the back side, as, for example, if it were held between the eye and a window, the grease spot will appear light on a dark ground, as shown in (*b*). If such a screen is mounted in place of the screen *C* in Fig. 11, and arranged so that both sides may be seen at once, the grease spot will disappear almost entirely when the two sides of the screen are equally illuminated. In order to facilitate the observation of the screen, it is usually arranged with two mirrors mounted at a slight angle to it, as shown at *M M* in (*c*). *S* is the screen with the grease spot, and the observer looks at the reflection of the two sides of the screen in the mirrors instead of the screen itself. This screen with the mirrors is mounted in a box, which is open at the ends to admit the light from the sources and which is also provided with an opening in the front to enable the observer to see the reflections of the screen.

25. Fig. 13 shows the arrangement of the parts of a simple photometer of the Bunsen type designed by Elmer G. Willyoung for use in connection with lighting stations. *A*, the standard—in this case an incandescent lamp of accurately known candlepower—is at one end, and *B*, the light to be measured, at the other; *D* is the bar on which the carriage containing the screen slides. The part *D* is usually spoken of as the **photometer bar.** *E* is the carriage containing the Bunsen screen. The motor *F* is used to spin the lamp *B* while measurements are being made; the reason for doing this will be explained later. *G* and *H* are two adjustable resistances for keeping the voltage applied to the lamps at the proper value.

26. Fig. 14 shows a Deshler-McAllister photometer—a simple instrument that has been quite largely used by lighting stations for testing the light-giving qualities of the lamps they are using. The principal difference between this

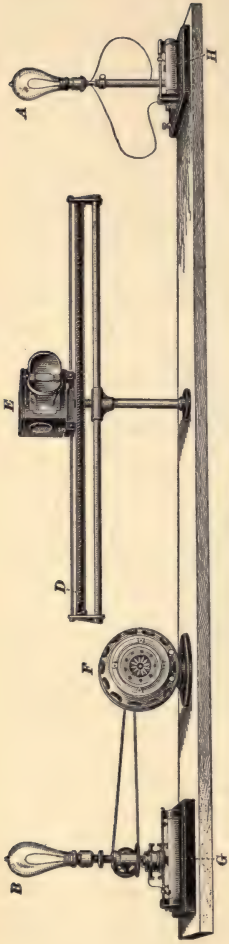


FIG. 13.

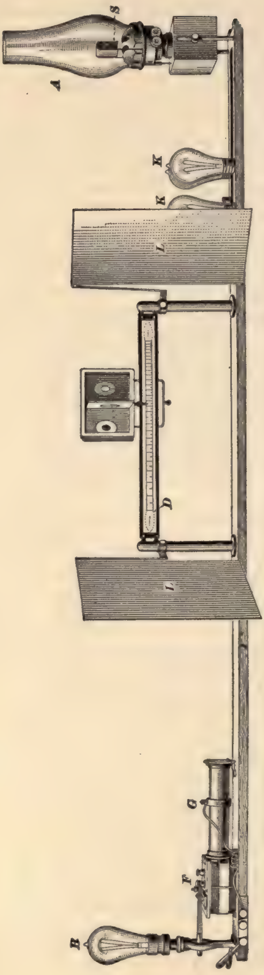


FIG. 14.

instrument and the one previously described is that an oil lamp *A* is used as a working standard instead of an incandescent lamp. The bar is also provided with a scale reading directly in candlepower, though the Willyoung instrument could also be provided with a direct-reading scale if desired. One objection to using an incandescent lamp as a light standard is that its voltage must be constantly watched and kept at the proper amount. It is largely to get around this difficulty that the oil lamp *A* is used. This is an ordinary oil lamp provided with a double wick and an adjustable screen *S*, by means of which the upper and lower ragged edges of the flame are cut off. *K*, *K* are standard incandescent lamps that have been accurately calibrated at the lamp factory and of which the candlepower at the voltage marked on them is known. Each of these standard lamps in succession is placed at *B* and the pointer of the carriage set at the point on the bar corresponding to the candlepower marked on the lamp. The voltage at the lamp is then adjusted by means of the rheostat *G* until it corresponds exactly with that marked. When this has been done, the screen *S* in front of the flame of *A* is adjusted until the grease spot is balanced. The lamp *A* is then of the same candlepower as the standard and may be used for the measurement of other lamps, since after it is once adjusted it is not likely to change, though it should be checked up now and then to make sure that it does not do so. The object in having a number of standard lamps *K* instead of one only is to have a check against any errors that might be caused by changes in the lamps. Screens *L*, *L* are provided to cut off the light from the observer's eyes and a motor *F* is used to rotate the lamp. These station photometers are not expensive, and if properly used, are of great value in detecting poor lamps.

27. After a person has become accustomed to the photometer, good results can be obtained provided the following conditions are fulfilled:

1. The lights, both the standard and the light being measured, should be steady.

2. The standard and the light being measured should be of approximately the same color.

3. The brightness of the light being measured and that of the standard should not differ to an extreme degree; for example, good results could not be expected if an attempt were made to compare an arc lamp with a candle.

Most ordinary photometer bars are fitted with a scale divided into equal divisions, as shown in Fig. 11, so that the distances may be read off and the candlepower calculated from these distances and the known candlepower of the standard. If the standard used is always of the same value, it is evident that the bar might be graduated to read directly in candlepower, as in the photometer shown in Fig. 14. Where a large number of lamps are to be tested, this can usually be done, as the same standard can be used all the time and readings taken rapidly from the bar as soon as the setting of the screen is made. Many modifications of the photometer have been made, but the above will give a general idea of the principles involved and of some of the forms especially useful in connection with electric-light stations.

LIGHT DISTRIBUTION.

28. Mean Horizontal Candlepower.—If an incandescent lamp be set upon a photometer and its candlepower measured, it will be found that different values for the candlepower will be obtained, depending on the position of the lamp and the shape of the filament. For example, in Fig. 15 the brightness of the lamp in the different horizontal directions *1*, *2*, *3*, *4*, etc., would not be the same. The candlepower given out in the different horizontal directions along any line, such as those shown in Fig. 15, is known as the **horizontal candlepower** for that position. The mean or average horizontal candlepower is the average value of these different readings. This mean horizontal candlepower is sometimes obtained by taking the reading from the lamp while it is rapidly revolved about its vertical axis. The

photometers just described are arranged so that the lamp may be revolved at the rate of about 180 revolutions per minute, thus giving the average, or mean, horizontal candlepower. The horizontal candlepower does not vary greatly in different directions with lamps as now constructed. This

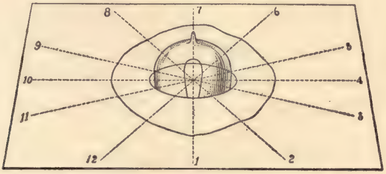


FIG. 15.

is shown by the irregular curve (Fig. 15). The distance of the points on this curve from the center represents the candlepower in the direction of the radius from that point, and if the candlepower were the same in all directions, this curve would become a circle.

29. Vertical Distribution.—Fig. 16 shows the readings for the candlepower obtained in a vertical plane with a filament in the position shown. It will be noticed that, viewed from position *1*, the candlepower is practically zero, because the light is almost completely cut off by the base of the lamp. At points *2* and *4* it is a maximum, because viewed from these points the maximum amount of the filament is seen. At point *3* the candlepower again drops off, because here the filament is seen end on. The curve of horizontal distribution gives an idea as to how the lamp throws light

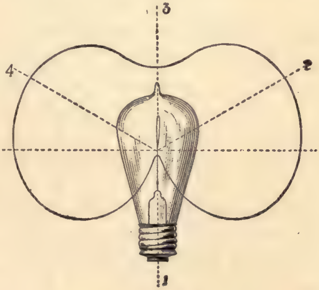


FIG. 16.

in a horizontal plane, and the curve of vertical distribution shows how the lamp behaves as to throwing the light up or down. In speaking of the candlepower of an incandescent lamp, the mean horizontal candlepower is usually meant, and this is most readily obtained by spinning the lamp as described above. In many cases, however, it is customary to measure the candlepower in one direction only, and the error in doing so is not usually very great, because filaments are nearly always twisted and the candlepower does not

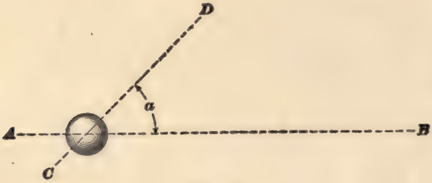


FIG. 17.

vary greatly when the lamp is viewed from different directions. In case the lamp is not revolved when measurements are being taken, it should be adjusted with the plane of its filament at such an angle to the photometer bar as will give the mean candlepower. For example, in Fig. 17 suppose that $A B$ represents the axis of the bar and that we are looking down on the top of the lamp. The line $C D$ will indicate the relative position of the plane of the filament. The angle a at which the filament should be inclined will depend on the style of filament used. For plain loop filaments it should be about 60° and for spiral filaments 30°.

30. Mean Spherical Candlepower.—It has just been shown that the intensity of illumination given by a lamp in different horizontal directions varies. Also, its value is different for the various directions taken in any vertical plane passing through the axis of the lamp. If we imagine a lamp hung so that it may be viewed from any direction, it is clear that if we viewed it from any number of different points we would get different values for the candlepower

If we took a large number of such readings at regular intervals and averaged them up, we would have what is known as the **mean spherical candlepower** of the lamp. In other words, the mean spherical candlepower represents that intensity of illumination to which the irregular illumination of the lamp would be equivalent if it were an average candlepower given out uniformly *in all directions.* In connection with commercial measurements on incandescent lamps, the mean spherical candlepower is not used to any great extent. It is used more in connection with arc lamps. One arc lamp may give a widely different spherical distribution from another, and in comparing such lamps, the mean spherical candlepower forms the fairest basis of comparison.

31. Incandescent lamps are made in a variety of sizes, the most common candlepowers being 4, 8, 10, 16, 20, 32, 50, and 100. The 16-candlepower lamp is the one most generally used. Small lamps of $\frac{1}{2}$, 1, and 2 candlepower are also used for decorative and advertising purposes.

PROPERTIES OF INCANDESCENT LAMPS.

32. Temperature.—The temperature at which the filament of a lamp is worked may be anywhere from 1,250° to 1,350° C. The hotter the filament is worked the greater is its light-giving power per watt consumed. Of course, it is desirable to operate a lamp so that it will give a large amount of light per watt, provided this can be done without injuring the lamp. At a temperature of about 1,350°, an ordinary lamp will give about $\frac{1}{3}$ candlepower per watt consumed; a 16-candlepower lamp would at this rate take 48 watts, or 3 watts per candle. At a temperature of 1,300°, the same lamp might give about $\frac{1}{4}$ candlepower per watt and thus require 64 watts for its operation. Although it is thus advantageous, as far as power consumption goes, to work the lamp at a high temperature, it is found that if the temperature is pushed too high, the life of the lamp is greatly

shortened. On the other hand, if the lamp is worked at a very low temperature; it gives a small amount of light compared with the power consumed, and although its life may be long, it is not satisfactory as a light-giving source.

33. Efficiency.—When the efficiency of an incandescent lamp or arc lamp is spoken of, the power consumption per candlepower is meant. For example, if an incandescent lamp required 3.5 watts for each mean horizontal candlepower, its efficiency would be 3.5, or it would be spoken of as a 3.5-watt lamp. This is not a very satisfactory method of expressing efficiency, because, according to this, the larger the power consumption per candlepower, the greater is the efficiency; while in point of fact just the reverse is the case. A much better way to give the efficiency would be to express it as so many candlepower per watt, and in some cases it is expressed this way. Evidently, the greater the number of candlepower per watt consumed, the greater is the efficiency. At present, however, efficiency is nearly always expressed as so many watts per candle. The power consumption per candlepower varies considerably. If the filament is worked at a high temperature, we may get 1 candlepower for every 2.75 watts expended, or even less, but such lamps are apt to have a short life and, in any event, require very steady voltage regulation. In ordinary work, lamps give about .3 candlepower per watt, i. e., they require about 3.33 watts per candlepower. This is a fair value for the power consumption of an ordinary lamp. A lamp may take as low as 3 or 3.1 watts per candlepower when first installed, but its light-giving properties fall off after it has been in operation for a time and the power consumption may run up as high as 3.8 or even 4 watts per candle. From 3.3 to 3.5 watts per candlepower is, therefore, a fair average.

34. Connections for Testing.—When testing lamps, a careful record should be kept of the length of time they have burned, also of the voltage and current. With this data at hand, together, of course, with the readings of candlepower as given by the photometer, the efficiency of the lamp at any

time during the test may be at once determined. Accurate instruments must be used, and their scales should be so divided that the ammeter or mil-ammeter may be read to $\frac{1}{1000}$ ampere and the voltmeter to $\frac{1}{10}$ volt. A variable resistance should also be inserted in series with the lamp so that the voltage across the lamp terminals may be kept nearly constant.

Fig. 18 shows the general scheme of connections. The ammeter *A* is connected in series with the lamp and the voltmeter *V* across its terminals. Readings of *A* are taken with the voltmeter cut out, so that *A* does not measure the current through the voltmeter as well as that through the

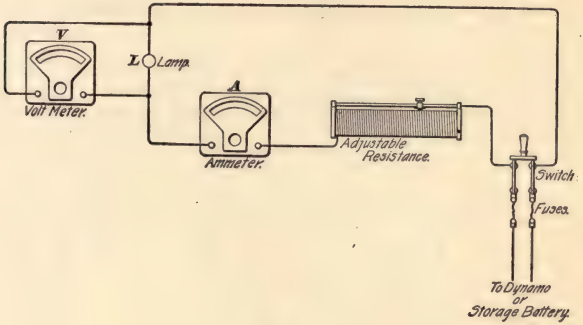


FIG. 18.

lamp. A good ammeter and voltmeter are to be preferred to a wattmeter for this kind of work, as the results are more likely to be accurate. Continuous current should, if possible, be used for all testing, as alternating-current instruments are more likely to lead to inaccurate results. Current supplied from a continuous-current dynamo running at constant speed may be used, but it will be found more satisfactory to use current from a storage battery if it can be obtained, as the latter current is perfectly steady. Readings of candle-power, current, and voltage should be taken as nearly simultaneously as possible.

35. Lamp Estimates.—With an average power consumption of 3.3 watts per candlepower, a 16-candlepower lamp would require $16 \times 3.3 = 52.8$ watts. The current that the lamp will require will depend on the voltage at which it is operated. The current in any case can be obtained by the following formula or rule:

$$C = \frac{CP \times W}{V}, \qquad \textbf{(3.)}$$

in which CP = candlepower, W = watts per candlepower, and V the voltage across the lamp terminals.

Rule.—*Multiply the candlepower of the lamp by the watts per candlepower and divide by the voltage at which the lamp is designed to operate.*

EXAMPLE.—A 32-candlepower lamp requires 3.5 watts per candlepower and is designed to operate at a pressure of 110 volts. What will be the current taken by the lamp and what will be the resistance of the lamp when hot?

SOLUTION.—From the above rule, we have

$$\text{Current} = \frac{32 \times 3.5}{110} = 1.02 \text{ amperes, nearly. Ans.}$$

From Ohm's law we have $C = \frac{E}{R}$, or $R = \frac{E}{C}$;

hence, $$\text{Resistance} = \frac{110}{1.02} = 107.8 \text{ ohms. Ans.}$$

NOTE.—The value of the resistance of an incandescent lamp obtained by dividing the E. M. F. by the current flowing through it gives the hot resistance. The resistance of carbon decreases as the temperature increases. Since the temperature is high in an incandescent lamp, the cold resistance is very much higher than the hot; it may be almost double the hot resistance. In practical work, we are not, as a rule, concerned directly with the cold resistance of the lamps, and when the resistance is spoken of, the hot resistance is meant. A 16-candlepower 110-volt lamp has a hot resistance in the neighborhood of 220 to 250 ohms.

Small incandescent lamps require a larger number of watts per candlepower than large ones. For example, a 4-candlepower lamp requires in the neighborhood of 20 watts; a 6-candlepower, 25 watts; an 8-candlepower, 32 watts; and a 10-candlepower, 37 watts. In general, then, the substitution of a

small lamp for a larger one will result in a saving in power, but not in direct proportion. For example, if an 8-candlepower lamp were substituted for a 16-candlepower, the power consumption might be reduced from about 52.8 watts to 32 watts and the candlepower would be cut down one-half.

36. If we allow for loss in the line, it will probably require at least 60 watts at the dynamo terminals for every 16-candlepower lamp operated. Hence, if the output of the dynamo, in kilowatts, is known, the number of 16-candlepower lamps that it is capable of operating may be obtained approximately by the following formula or rule:

$$\text{No. of 16-c. p. lamps} = \frac{K\,W \times 1{,}000}{60}, \qquad \textbf{(4.)}$$

in which $K\,W$ is the capacity of the dynamo in kilowatts.

Rule.—*Multiply the capacity of the dynamo in kilowatts by 1,000 and divide the result by 60. The quotient will give approximately the number of 16-c. p. lamps that the machine is capable of operating.*

EXAMPLE 1.—About how many 16-candlepower lamps should a 12-kilowatt dynamo be capable of operating?

SOLUTION.—

$$\text{Number of lamps} = \frac{12 \times 1{,}000}{60} = 200. \quad \text{Ans.}$$

Sometimes the output of the dynamo is given in volts and amperes instead of in kilowatts. In such cases, the output in *watts* is easily obtained by multiplying the volts by the amperes, and the number of 16-candlepower lamps that the dynamo can operate may then be obtained by dividing by 60 as before.

EXAMPLE 2.—A dynamo is capable of delivering an output of 70 amperes at a pressure of 115 volts. About how many 16-candlepower lamps can it run?

SOLUTION.—The output in watts will be $115 \times 70 = 8{,}050$, and since each lamp requires about 60 watts, the capacity of the machine will be $\frac{8050}{60} = 134$. Ans.

NOTE.—When the capacity of a dynamo is given as so many lamps, 16-candlepower lamps are always meant. If 32-candlepower lamps are operated, each 32-candlepower lamp should be counted as the equivalent of 2 of 16-candlepower.

37. The number of indicated horsepower required at the steam engine to operate a given number of lamps will depend on the amount of power lost in the dynamo and engine. The approximate rule given above supposes that 60 watts are required at the terminals of the dynamo for each lamp operated. There will be some loss in the dynamo and in the engine, so that the indicated power per lamp at the cylinder of the engine must be more than 60 watts. Just what this indicated power per lamp must be will depend on the combined efficiency of the engine and dynamo, and this will, in turn, depend on the size and type of engine and dynamo. Generally speaking, ten 16-candlepower lamps can be operated per indicated horsepower; this number may be exceeded somewhat with very economical engines and dynamos, while, on the other hand, with poor apparatus the lamps per indicated horsepower may fall below the number given.

EXAMPLE.—An isolated plant is to be installed for operating 350 16-candlepower lamps. (*a*) What should be the indicated horsepower of the engine? (*b*) What should be the approximate capacity of the dynamo in kilowatts?

SOLUTION.—(*a*) Allowing 10 lamps per indicated horsepower, the horsepower of the engine would have to be $\frac{350}{10} = 35$.

(*b*) Allowing 60 watts at the dynamo terminals per lamp, the output in watts would be $350 \times 60 = 21{,}000$, or 21 kilowatts. Ans.

38. Life.—The length of time that an incandescent lamp will burn before giving out is very uncertain and depends on a number of different things. Sometimes there may be defects in the manufacture that will cause a lamp to burn out in a very short time, though systematic testing at the factory has resulted greatly in the reduction of the number of such lamps that reach the consumer. Lamps are often run at a higher voltage than they should be, and although this makes them give a good light for the time being, it shortens their life greatly. Raising the pressure 1 or 2 volts above the proper amount on a 110-volt lamp may shorten its life as much as 15 to 25 per cent. On the other hand, it does not pay the central station to run the voltage

low, because, although the lamps may last longer, they will not give a good light and will give rise to dissatisfaction on the part of the customers. It is always best to run the lamps as nearly as possible at the voltage for which they are designed, and to run the plant so that the regulation will be good, i. e., so that the voltage at the lamps will be nearly constant, no matter how the number of lamps in use may vary.

39. Assuming, however, that the voltage is kept at the proper amount, the lamp will gradually fall off in brilliancy after it has been burned for some time, and after a certain point is reached the lamp becomes so uneconomical that it pays better to replace it by a new one rather than attempt to run it until it burns out. The length of time during which it pays to burn a lamp is difficult to decide. Lamps will frequently burn over 2,000 hours before they give out, but after they have burned from 500 to 700 hours their candlepower has fallen off to such an extent that it will probably pay to replace them. Many large central stations make it a rule to replace lamps when they have fallen off to 80 per cent. of their original candlepower. For example, a 16-candlepower lamp would be discarded when it had fallen off to 12.8 candlepower.

40. The falling off in candlepower is generally attributed to a disintegration of the carbon. The filament gradually increases in resistance on account of small particles of carbon being thrown off; this increase in resistance results in a decrease in current and, consequently, in a falling off in candlepower. Moreover, the small particles of carbon are deposited on the inside of the globe, thus producing the well-known blackening effect and further reducing the illuminating capacity of the lamp. Lamps have been very much improved of late years as regards this falling off in candlepower. The two curves, Fig. 19, given by Mr. F. W. Willcox,* illustrate the improvement in this respect, the

* See Journal of Franklin Institute, April, 1900.

upper curve being for a modern lamp and the lower for an old-style lamp. Both lamps start out with the same candlepower, and the lines show the percentage of the initial candlepower after the lamps have been burning for different intervals of time. There is a steady decline in the light of the old lamp from the time it starts burning, and at the

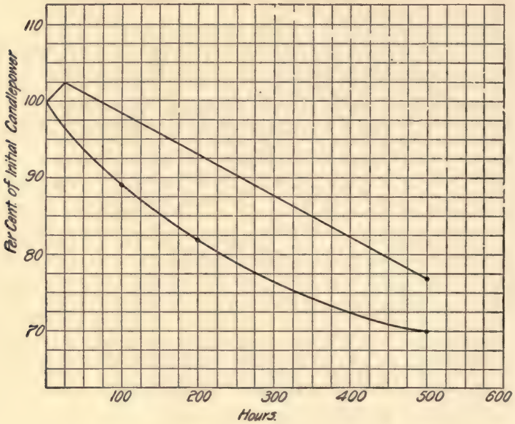


FIG. 19.

end of 500 hours it is only giving 70 per cent. of the light it gave at the start. The candlepower of the other lamp, on the contrary, increases slightly during the first 25 hours, and at the end of 75 hours has gotten back to its original candlepower. It then falls off in candlepower, but at the end of 500 hours is still giving about 77 per cent. of the original amount.

41. Voltages.—The voltage of an incandescent lamp is the pressure that must be maintained between its terminals in order that the resulting current shall cause the lamp to give its rated candlepower. By far the greater number of

incandescent lamps in use are designed for voltages anywhere between the limits of 100 and 115 volts. For example, 100, 104, 110 are common values. When alternating current was first introduced, it admitted the use of low voltages at the lamps, because the current could be transmitted at high pressure and then transformed to low pressure. At that time, it was more difficult to make durable and efficient lamps for 100 or 110 volts than for lower voltages, and a pressure of 50 or 52 volts for the lamps became common. This pressure is not being used on new installations, because there is now no difficulty in making lamps for the higher voltages. A pressure of 80 volts is commonly used for marine work. Of late years, it has become possible to make lamps for 220 to 250 volts, and a number of plants using lamps of this voltage are in successful operation.

In connection with lamp voltages, it may be interesting to note that in the process of manufacture it is impossible to make all the lamps come out at the voltage aimed at. For example, if a lot of 110-volt lamps were to be made up, a great many of them would come out at 108, 109, 111, or thereabouts. It is often a good plan, therefore, for a station to operate at an odd voltage of, say, 107 or 111 rather than at 110, as the chances are that if lamps are ordered for the odd voltages they will be obtained, whereas, if ordered for the even 110 volts, it is probable that 108-volt or 109-volt lamps marked 110 will be supplied, because it would be practically impossible to supply all the lamps of exactly 110 volts without especially selecting them.

42. General Remarks.—Incandescent lamps are made for a wide range of voltage and candlepower. The power consumption per candlepower also varies through wide limits. High-efficiency lamps, in general, will have a short life unless the voltage regulation is very good; hence, high-efficiency lamps should not be used in places where the regulation is poor. In order to determine the current that any lamp will take, its power consumption per candle must be known, and the current may then be calculated as

explained in Art. **35.** When making wiring estimates, or, in any case, when the approximate current only is needed, the following values of the current required per lamp may be used:

TABLE I.

Candlepower.	Voltage.	Current. Amperes.
10	110	.36
16	110	.50
32	110	1.00
10	52	.75
16	52	1.00
32	52	2.00

43. Heating.—A 16-candlepower, 64-watt incandescent lamp gives off about 220 British thermal units of heat per hour.

A British thermal unit is equivalent to the amount of heat that is required to raise 1 pound of water from 62° F. to 63° F.

Incandescent lamps give off between 5 and 10 per cent. of the heat emitted by gas-jets of the same candlepower.

44. Illumination by Incandescent Lamps.—In all methods of wiring, it is necessary to so locate the light that the best illumination may be obtained. In factory lighting, the lights are so placed that they will be as near as possible to the workmen, whether at the machine or vise.

For the interior of stores, general illumination is required. Show windows should be lighted by reflected light only, because exposed light striking the eye will cause the effect of the general arrangement to be lost to the observer. In picture galleries, this same idea should be carried out. House illumination is more for effect than general illumination.

In theater lighting, where the scenic effects depend

entirely on a careful adjustment of light intensities, experience is the only guide.

Among other points to be observed in placing lights is the color of the surrounding walls. Dull walls will reflect only about 20 per cent. of the light thrown on them, while a clean, white surface will reflect 80 per cent. The height of the room also reduces the effectiveness of a given light intensity.

One **candle-foot** is considered a good light to read by, which is the illumination given by a standard candle at the distance of 1 foot.

The illuminating value of different lights is as follows:

TABLE II.

Light.	Candle-Feet.
Ordinary moonlight.......	.025
Street lighted by gas......	.030
Stage of theater	2.9 to 3.8
Diffused daylight.........	10.0 to 40.0

A clear idea of these various intensities is easily gained by comparison, remembering that *1 candle-foot* furnishes a good light to read by, as stated above.

THE NERNST LAMP.

45. Many attempts have been made to improve the efficiency of incandescent lamps. The efficiency of any light-giving source depends on the temperature of the substance that emits the light. If the temperature is increased, the amount of energy given off in the shape of light becomes greater in proportion to the amount given off as heat, and the efficiency of the lamp as a light-giving source is improved. For example, an incandescent lamp worked above its normal voltage gives more candlepower per watt consumed than if

worked at a low voltage; but the high temperature soon burns out the filament. Many attempts have been made to produce filaments that could be operated at a higher temperature than carbon and thus make more efficient lamps. One of these is the **Nernst lamp.** This lamp has not as yet come into extended commercial use, so that we will confine ourselves to a brief description of its principle of action. There are some substances that, while they are good insulators when they are cold, become fairly good conductors when heated to a sufficiently high degree. Glass, for example, when heated to a red heat will conduct electricity. Oxide of magnesium (magnesia), thoria, and a number of other oxides will also conduct electricity when they are heated.

The "glower," or light-giving portion of the Nernst lamp, is a small stick made of oxide of magnesia, thoria, or similar substance. When this stick is heated it conducts current, and this brings the oxide up to a very high temperature, thus making it give light. The temperature attained by the oxide stick is very much higher than that of the incandescent-lamp filament, and the lamp is therefore far more efficient. It is necessary, however, to have a small amount of resistance in series with the glower, in order to make the action of the lamp stable, and this tends to lower the efficiency to some extent. The glower is protected by a small glass globe, but the air is not exhausted. The substance giving the light is already an oxide, so that it cannot be further oxidized by being in contact with the air, and there is no need of placing it in a vacuum. One disadvantage of the lamp is that the glower must be heated before the lamp will start. Various devices for accomplishing this initial heating electrically have been brought out. In the Westinghouse type of Nernst lamp, the glower is heated by being placed directly under a coil of platinum wire wound on a small cylinder of refractory material. When the current is turned on, it heats this coil and thus raises the temperature of the glower until it is able to conduct current. After the glower has started, the heating coil is cut out automatically.

It requires from 15 to 30 seconds for one of these lamps to start. The light given by the Nernst lamp is of a pleasing color, and 1 candlepower can be produced with an expenditure of 1.50 to 2 watts.

METHODS OF CONNECTING LAMPS.

46. Lamps in Parallel.—By far the greater number of incandescent lamps are connected in parallel, as shown in Fig. 20. When lamps are connected in this way, the pressure between the two lines must be kept at a constant value, because if this is not done, the current flowing through the lamps will vary. It must be remembered that the resistance of the lamp cannot change, unless the temperature of the filament changes, because the filament is of fixed dimensions. The current that will flow through any lamp depends on two things, and only two, namely: the pressure between the lines and the resistance of the lamp. The current in each lamp will be equal to the pressure between the mains divided by the resistance of the lamp. So long as the pressure is kept constant, it is easy to see that the turning off or on of any lamp does not affect the others. The current C flowing in the mains will increase when lamps are turned on and decrease when they are turned off. As stated above, practically all incandescent lamps are connected in this way, because such an arrangement is extremely simple, and each lamp is independent of the others.

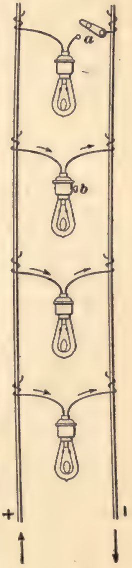


FIG. 20.

47. Lamps in Series.—Lamps are occasionally connected in series, as shown in Fig. 21. This arrangement is used principally for street lighting; it is seldom used for interior work for reasons that will appear later. In this case, the same current flows through all the lamps; hence,

their filaments must all be of the same current-carrying capacity. If it is desired to have some lamps of higher candlepower than the others, their filaments must be made longer. The pressure across the terminals of any lamp may be found by multiplying the resistance of the lamp by the current flowing. Also, since the lamps are connected in series, the total pressure required to force the current through the circuit will be the sum of the pressures required for the separate lamps. For example, suppose we had 10 lamps, each requiring a pressure of 20 volts and a current of $3\frac{1}{2}$ amperes; also, 5 lamps each requiring a current of

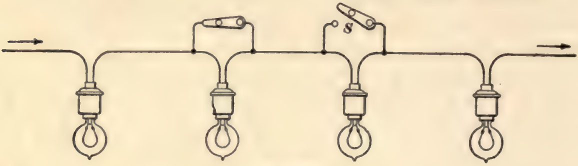


FIG. 21.

$3\frac{1}{2}$ amperes and a pressure of 40 volts. The total pressure required for the circuit, neglecting the loss in the line, would then be $20 \times 10 + 5 \times 40 = 400$ volts. In this system, the line current is small; hence, it is well adapted for incandescent street lighting, where the area to be covered is large. It should be noted that in a system of this kind the current must be maintained at the value for which the lamps are designed. This means that the pressure between the ends of the line must be raised as more lamps are added to the circuit, because the resistance is increased. Also, the pressure must be lowered when lamps are cut out, otherwise the current would increase and burn out the remaining lamps. In the series system, the current is constant and the pressure varied so as to keep it constant; in the parallel system, the pressure is kept constant and the current varies as the number of lamps in use is increased or decreased. Another point to be noted in connection with the series system is that some means must be provided for maintaining the circuit around the lamps, in case they should burn out;

otherwise, the breaking of any one lamp would put out all the lights on the circuit. The method by which this is accomplished will be described when this system is taken up in detail. The student will also note that if the number of lamps operated is at all large, the pressure applied to the circuit may be very high. This introduces an element of danger and is the principal reason why series lighting is not used for interior work. Lamps in series may be cut out of circuit by short-circuiting them as indicated by switch *S*, Fig. 21; whereas, in the parallel system they must, of course, be cut out by opening the circuit through the lamp by means of a switch in series with it. This switch may be a separate device, as at *a*, Fig. 20, or it may be in the lamp socket and worked by a key, as at *b*.

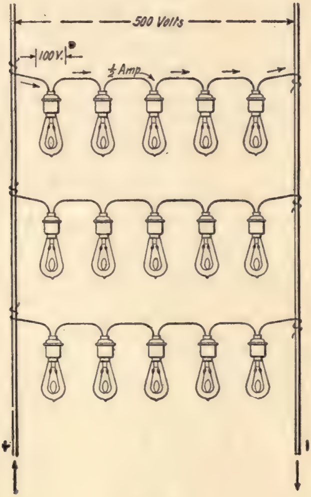


FIG. 22.

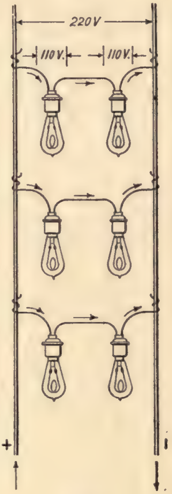


FIG. 23.

48. Lamps in Multiple Series.—This method, sometimes called **parallel series,** is a combination of the two

preceding and is used in a number of special cases. Perhaps its widest use is in connection with the lighting of electric street cars; it is also used in mine-lighting work, where lights are operated fro n the haulage system. This multiple-series scheme of connection is shown in Fig. 22. Suppose, for example, that we have a pair of mains between which a constant pressure of 500 volts is maintained, as on a street railway, and that we wish to operate incandescent lamps on such a circuit. We cannot obtain lamps for 500 volts and a single 100-volt lamp would be burned out instantly if it were connected across the mains. If we wish to use 100-volt lamps, we may connect five of them in series, as shown. With such an arrangement, the current through the series of five lamps would be about ½ ampere and the pressure across each lamp 100 volts. We may connect any number of such series of five lamps across the mains, and if one light goes out, it puts out the other four in the same circuit with it. Also, if any lamp were cut out, by short-circuiting it, the voltage on the other four lamps would become higher than they could stand, because the pressure between the mains is constant, and cutting out the drop through one lamp simply throws that much more pressure on the others. As stated above, this method of connecting lamps is used principally in places where it is desired to operate lamps on power circuits, the voltage of which is usually higher than that of the lamp. Fig. 23 shows a multiple-series arrangement with two lamps in series, a scheme of connection sometimes used for operating lamps on 220-volt power circuit, for example, in mine-haulage plants. By adding the middle, or neutral, wire to Fig. 23, we get the three-wire system, Fig. 24, so extensively used for distribution in large cities.

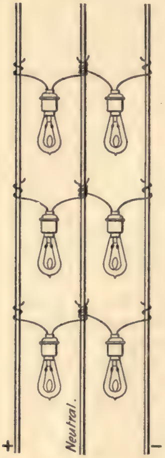


FIG. 24.

The schemes of connection given above cover most of the cases met with in practice. Their use in connection with the different systems of distribution will next be considered.

SYSTEMS OF DISTRIBUTION.

49. It will be necessary to take up at this point the different systems commonly used for supplying the electrical energy to the lamps. The methods of distributing the current to the lamps by means of the wiring in the building will not be considered here, as that part of the subject belongs properly to interior wiring and will be taken up in connection with that subject. The following brief descriptions of the more important distributing systems are intended to point out how the methods already described are applied to electric-lighting work. Current for electric lighting is distributed from the station to the point of utilization in the same manner as for power transmission; in fact, in the majority of cases the electric energy transmitted is used both for lighting and power purposes.

With but few exceptions, the current required for the operation of incandescent lamps is distributed at a constant potential, i. e., the aim is to keep the pressure at the station such that the pressure at the lamps will remain constant no matter what the load may be. If the pressure at the lamps is not maintained uniform within narrow limits, the service will be poor, the life of the lamps short, and the complaints from customers numerous. Where the lamps are run on a constant-potential system, the current transmitted over the lines increases with the load, because every light turned on means just so much more current to be supplied. The consequence is that the drop in the line increases with the load, and in order that the pressure at the lamps shall be maintained constant instead of falling off on account of this drop, the pressure at the dynamo or station must be raised slightly. In any event, no matter what means may be adopted for distributing the current, the aim should

be to provide the lamps with a uniform pressure and to see that this pressure is kept uniform, no matter how the number of lamps operated may vary. The distribution should also be designed so as to accomplish the object aimed at with the least possible expense, i. e., the distributing lines should be laid out so as to secure the desired results with the smallest possible amount of copper and loss of energy.

DIRECT-CURRENT CONSTANT-POTENTIAL SYSTEM.

50. Simple Two-Wire System.—This method of distribution is very largely used for small, isolated plants, or any installation where the power is transmitted a short distance only. The lamps are usually operated at 110 volts and the current is supplied by compound-wound dynamos. Fig. 25 shows a single dynamo *G* operating lamps on the

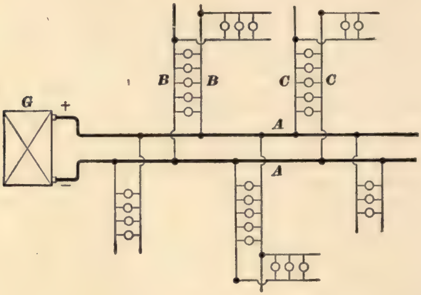


FIG. 25.

simple two-wire system. In this case, two main wires *A*, *A* run from the dynamo, the various switches and measuring instruments being here omitted for the sake of clearness, and the lamps are either connected directly across this pair of mains or are connected across branch mains, as shown at *B*, *B* and *C*, *C*. The lamps are, therefore, simply

connected in parallel, as explained in Art. **46.** This arrangement answers very well for small plants, where only a small number of lamps are operated and where they are not scattered very widely.

51. Feeders and Mains.—If the lamps are scattered over a considerable area, it is best to run out feeders, as shown at *A* and *B*, Fig. 26, to what is known as **centers of distribution,** as at *C* and *D*, and then at these points attach mains *E*, *F* to the feeders. These centers of distribution should be selected so as to lie near the points where the bulk of the light is used. It will be noticed that no lights whatever are attached to the feeders; they simply

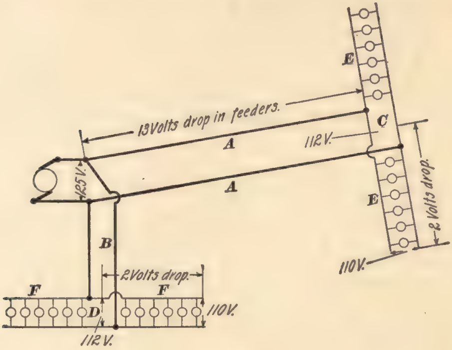


FIG. 26.

convey current from the station to the center of distribution, which becomes, as it were, a kind of substation. By this method, a considerable drop can be allowed in the feeders without causing any trouble at the lights. For example, suppose 110-volt lamps were to be operated and a drop of 15 volts was allowable between the dynamo and the last lamp on the line. We may, for example, figure the cross-section of the feeders so that a drop of 13 volts will occur in them. This large drop will allow comparatively

small feeders to be used and will not be injurious to the lamps, because the pressure at the point *C* will be maintained at 112 volts, and the variation in pressure along the mains would be but 2 volts, or the balance of the total drop of 15 volts allowed. It is evident that when no current is flowing, there can be no drop in the line, because the drop is the product of the current and the line resistance. As the current increases, the drop increases, so that in the above case the dynamos would have to be adjusted to give a pressure of 110 volts at no load and 125 volts at full load; in other words, the dynamo would be overcompounded so as to give a rise in voltage of 15 volts.

52. The arrangement just described is known as the **feeder-and-main system,** and the advantages of such a system may be summed up briefly as follows:

1. It allows the use of a large drop in the feeders carrying the current to the point where it is distributed, thus permitting the use of comparatively small conductors and thereby cutting down the expense.

2. It allows this large drop without introducing large variations in the voltage obtained at the lamps.

3. It allows the district lighted to be divided into sections, each supplied by its own feeder, and thus admits of each section being controlled independently from the station.

53. Three-Wire System.—The simple two-wire system, even if operated on the feeder-and-main plan, requires altogether too much copper to admit of very extended use. For moderate distances, the three-wire system is used. Fig. 27 shows this system using feeders and mains as applied to lighting work. A large amount of lighting is carried out on this plan in New York, Philadelphia, and other large cities. It is not confined to direct current alone, but is also largely used in connection with alternating current. We have here the two dynamos *A* and *B* connected in series and supplying current through the feeders *1*, *2*, *3*, etc. to the different centers of distribution where the mains *a*, *b*, *c* are

attached. The use of this arrangement effects a considerable saving in copper over the two-wire system; the pressure commonly used is 110 volts on each side of the circuit, or

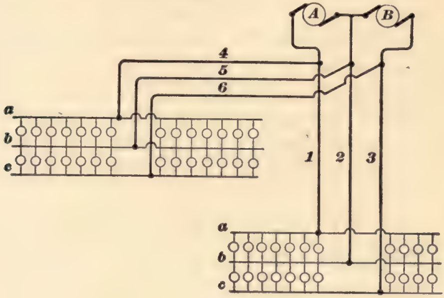


FIG. 27.

220 volts between the outside wires. In some recent plants, 220-volt lamps are used, thus giving 440 volts between the outside wires.

54. Special Three-Wire Systems.—The ordinary three-wire system has the disadvantage of requiring two dynamos. If the load were absolutely balanced, one 220-volt dynamo would alone be sufficient, but in most cases an accurate balance cannot be obtained. A number of different systems have been devised whereby a large 220-volt dynamo can be operated on the two outside wires and the unequal distribution of the load taken up by a balancing arrangement of small capacity compared with that of the dynamo.

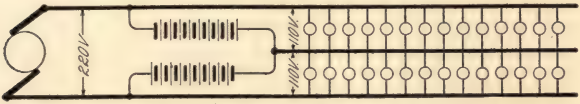


FIG. 28.

55. Fig. 28 shows one of these systems where the unbalancing in the load is taken care of by means of the storage

battery connected as shown. The middle point of this battery is connected to the line. The 220-volt dynamo is connected to the outside wires, and if a larger current is needed on one side of the battery than on the other, the extra current is supplied from the battery. It is not, however, generally advisable to use a battery in this way for maintaining the balance continuously as the cells become unevenly discharged. When batteries are used on three-wire systems, they are usually connected across the outside lines and a switch provided to connect their middle point with the neutral, so that they can be used for balancing in case of necessity.

56. Fig. 29 shows a three-wire system fed by a 220-volt dynamo A in conjunction with a motor-dynamo $a\,a'$. This motor-dynamo is sometimes called a **balancing set** or **balancer.** The armatures a, a' are mounted on the same shaft and connected in series, the mid-point n being connected to the neutral wire. The fields of these two machines are connected across the mains, as shown at $f\,f'$. When one side of the system is more heavily loaded than the other, the

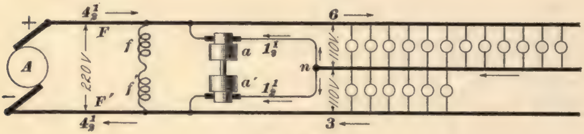


FIG. 29.

machine on the heavily loaded side runs as a dynamo and helps to supply current to that side, while the machine on the lightly loaded side absorbs power and runs as a motor, thus equalizing the load. Take, for example, the special case shown in Fig. 29, where we have 12 lamps on one side and 6 on the other. We will have 18 lamps to be supplied with power from the 220-volt machine A. Allowing 55 watts per lamp, this gives 55×18 watts and, hence, $\frac{55 \times 18}{220} = 4\frac{1}{2}$ amperes. The current flowing out on F and back

on F' must, therefore, be $4\frac{1}{2}$ amperes. The upper side of the three-wire system requires 6 amperes and the lower side 3, because we have 12 lamps in parallel in the one case and 6 in the other. We have, then, 3 amperes coming back through the neutral, of which $1\frac{1}{2}$ flows through a', running it as a motor and generating $1\frac{1}{2}$ amperes in a. This $1\frac{1}{2}$ amperes is added to the $4\frac{1}{2}$ in line F, thus making the 6 required for the upper side. By following the current as indicated by the arrows, the student will understand how the balance is maintained. If the lower side should become more heavily loaded than the upper, the current in the neutral wire would be in the opposite direction and the action of a and a' would be reversed; that is, a would act as the motor and a' as the dynamo. This motor-dynamo or balancer does not have to be placed in the station; it may be placed at a point near the center of distribution, thus requiring only the two feeders F and F' to be run back to the station, and thus avoiding the necessity of running the neutral wire all the way back, and thereby effecting a saving in copper. In the above illustration we have neglected the losses in the balancing set. As a matter of fact, machine A would furnish more than $4\frac{1}{2}$ amperes in order to make up for the losses in a a' and supply the lamps as well.

57. In most large stations operating on the three-wire system, the amount of unbalancing is usually small compared with the total load carried, so that the capacity of the balancing arrangement is, as a rule, small compared with that of the main dynamo. By far the greater part of the distribution on the three-wire system is, however, carried out by the ordinary two-dynamo arrangement shown in Fig. 27.

58. Voltage Regulation.—In stations where a large number of lamps are operated, it is usually necessary to have several distinct feeders running to the different districts to be lighted or supplied with power. Some of these feeders may be long, others quite short. In order, therefore, to keep the cross-section of the long feeders within a reasonable size, a larger drop must be allowed in them than in the

short feeders. It is necessary, then, to have some means of supplying the long-distance feeders with a higher pressure than those supplying the nearby districts. Of course, the voltage on the short feeders might be cut down by inserting resistance in series with them, and this, in fact, has been done in some cases. Such a method is, however, wasteful of power and is not to be recommended.

59. A common method is to use separate dynamos for supplying the long-distance feeders, and simply run these dynamos at a higher voltage than those supplying the short feeders. This is an excellent method where the separate

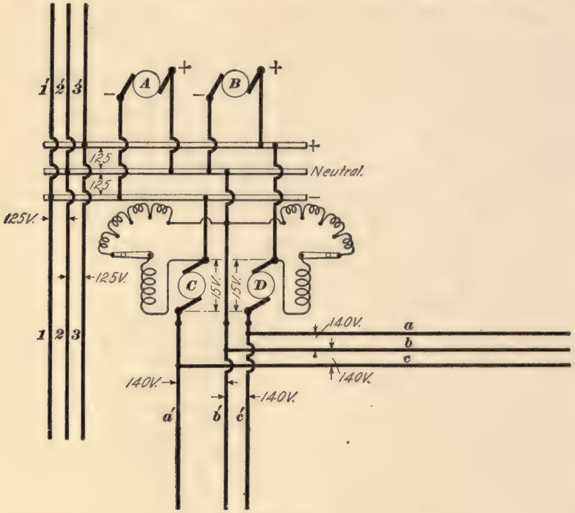


FIG. 30.

dynamos are available, but frequently this is not the case. When only one dynamo or set of dynamos is at hand for operating the whole system, the best plan is to run the machines at the lower pressure suitable for the short feeders, and use a "**booster**" to raise the voltage on the other

feeders. Fig. 30 will indicate what is meant by this arrangement. The plan shown is for the three-wire system, though the same scheme may be used on a two-wire system and is, in fact, largely used on such systems in connection with electric railways. In Fig. 30, *A* and *B* are two dynamos operating on the three-wire system and supplying current directly to the short feeders *1*, *2*, *3*, *1'*, *2'*, *3'*. Feeders *a*, *b*, *c* and *a'*, *b'*, *c'* run to outlying points and, therefore, must be supplied with a higher pressure than the other feeders. We will suppose, for example, that each dynamo generates 125 volts and that the long-distance feeders require 140 volts between the outside and neutral wire; 15 volts must, therefore, be added to each dynamo voltage. This is accomplished by the "boosters" *C* and *D* connected as shown. The boosters are small dynamos that are driven either by a steam engine or, more frequently, by an electric motor. The fields of these machines are separately excited from the mains and the armatures are connected in series with each of the outside wires, as shown. The armatures of the boosters must be capable of carrying all the current used on the long-distance feeders and be able to generate a pressure equal to that by which the voltage is to be raised. For example, in this case the booster armatures would generate the extra 15 volts required and thus give 140 volts on the feeders *a*, *b*, *c* and *a'*, *b'*, *c'*. By varying the field rheostat of the boosters, the voltage on the feeders may be adjusted. Boosters are about the same as other dynamos in general appearance, except that they usually have very large commutators and brushes compared with other dynamos of equal capacity, because they have to carry a large current through their armature. If the connections of the booster armatures were reversed, it is evident that they would lower the voltage instead of raising it.

60. Five-Wire and Seven-Wire Systems.—The three-wire system has been still further extended so as to make use of higher potentials by employing four dynamos in series and three neutral wires This allows the use of

440 to 500 volts between the outside wires and permits a still larger area to be covered than by the three-wire system. Seven-wire systems using six dynamos in series have also been used, and the five-wire system especially has been successfully applied on the Continent of Europe. Five-wire and seven-wire systems have been very little used in America, the practice being to use alternating-current methods of distribution if pressures higher than those given by the 110–220-volt or 220–440-volt three-wire systems are required. The use of three-wire systems with 220-volt lamps and 440 volts across the outside wires is gradually extending, because the higher pressure allows larger areas to be supplied and effects a saving in copper over the 110–220-volt system.

DIRECT-CURRENT, CONSTANT-CURRENT SYSTEM.

61. This system is very seldom used for incandescent-lighting work. It was in use to some extent in the early days of electric lighting, when a few incandescent lights were operated in series with direct-current arc lamps. In such systems, the current used was a direct one, furnished usually by a machine of the T. H., or Brush, type, and this current was maintained at a constant value by the variation in E. M. F. brought about by the automatic regulator. There were many objections to operating incandescent lamps in this way; each lamp had to be provided with a cut-out of some kind to prevent the circuit being broken in case a lamp burned out; such circuits also required a high pressure for their operation, and this rendered the use of incandescent lamps so operated dangerous for interior illumination.

ALTERNATING-CURRENT, CONSTANT-POTENTIAL SYSTEM.

62. Alternating current at constant potential is very extensively used for incandescent lighting, because this method allows lights to be operated over large areas with a

comparatively small loss and a small expenditure for copper. The distribution may be carried out either by means of the single-phase, two-phase, or three-phase system. If the current were intended for operating lights only, the single-phase scheme would be used, as it is simpler than either the two-phase or three-phase arrangements. Most modern lighting plants, however, are equipped so that they can operate motors as well as lights, and, hence, it is now customary to install multiphase systems rather than single-phase.

63. Single-Phase System.—When alternating current first came into use for electric lighting, a simple alternator was used to supply current at a constant pressure. This current was transmitted over the line, and at the various points where it was utilized, transformers were installed to step down the voltage to an amount suitable for the lamps. Each customer usually had his own transformer. If the system was small, only a single pair of lines or feeders was run from the station; in case the area lighted was large, a number of feeders supplying different sections were used, as previously described for the direct-current system. The pressures first used were 1,000 volts on the primary mains and 50 or 52 volts on the secondary. As the construction of alternators, transformers, and lamps was brought to a higher stage of perfection, the pressures were increased to 2,000 volts primary and 100 to 110 volts secondary. The frequency used in the early plants was usually from 125 to 133 cycles per second; in later plants, 60 cycles has become common practice.

64. The great advantage of this system over the direct current lies, of course, in the use of the high pressure for transmitting the current. The introduction of alternating current rendered possible the lighting of many places that could not afford the expense of installation that would be necessary if direct current were used. It also rendered available water-powers located at some distance from the center to be lighted.

65. It was formerly customary, in connection with systems of this kind, to install small transformers for each customer, as shown at *A*, *B*, *C*, Fig. 31, and if a large amount of current were required at any point, a number of transformers were connected in parallel, as shown at *K*. This was necessary because transformers were not then made in large sizes. On account of the objections, as before stated, to running a number of small transformers in parallel, it has become the practice to make use of a system of secondary mains supplying a number of customers and

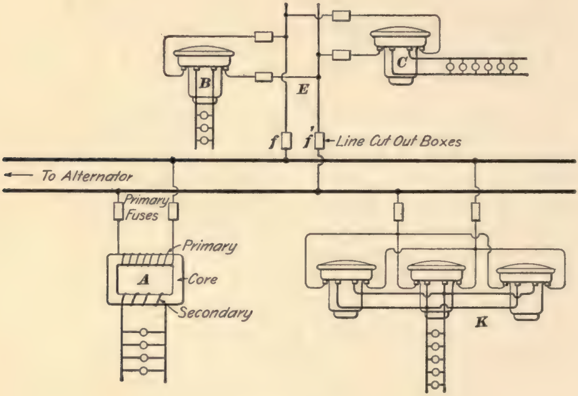


Fig. 31.

to feed these secondary mains from a few large transformers, as shown in Fig. 32. In this case, we have the primary mains *A*, *B* running from the station and feeding the large transformers *T*, *T*, as shown. The distributing secondary mains are usually arranged on the three-wire system, as indicated at *C*, thus allowing a considerable area to be supplied from one pair of transformers. The current may, however, be distributed by secondary two-wire mains

if the lights are close at hand. Scattered customers must, of course, be supplied by individual transformers, as in Fig. 31.

The small transformers are usually mounted on the pole outside the building to be lighted. Large transformers are mounted indoors or in substations. The use of secondary mains greatly reduces the number of transformers to be kept in repair and otherwise looked after; it also effects a considerable saving in power, owing to the higher efficiency of the large transformers. Where branch lines, as shown

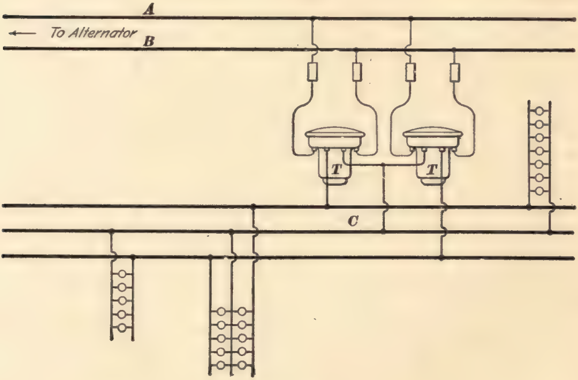


FIG. 32.

at E, Fig. 31, are taken off the main feeders, main-line cut-out boxes f, f' should be installed as indicated. The secondary-main arrangement can generally be used to advantage for furnishing light to the business part of a town, while in the residence part it is frequently necessary to use individual transformers on account of the customers being scattered. The above remarks in reference to secondary mains apply also to lighting systems using two-phase or three-phase distribution.

66. Two-Phase System.—This system of distribution for incandescent-lighting work has come largely into use, not because it is any better than the single-phase system, so far as the lighting is concerned, if, in fact, it is as good, but because it enables both lights and motors to be operated from the same dynamo. The general scheme of distribution is the same as that just described for the single-phase system. In a two-phase system of this kind, an effort should always be made to have the load balanced on the two phases, otherwise an uneven distribution of voltage is apt to result. Motors may be operated from the same lines as the lamps, but it is better practice to have separate feeders to supply the motors.

67. Three-Phase System.—This system was introduced for the same reason as the two-phase system, i. e., to permit the operation of motors. The ordinary three-phase system requires only three wires. In a few cases, however, where the load is liable to be unbalanced, a common return wire is used. The transformers may be connected according to any of the methods already described. Where three wires are run from the secondaries, the voltage between any pair of wires is the same, so that the lamps will burn with the same brilliancy across the outside wires as across either of the others; in this respect, therefore, it is different from an ordinary Edison three-wire system. Also, the voltage between any pair of the primary wires is the same, whereas in the three-wire, two-phase system, the pressure between the two outside wires is about 1.414 times as great as the pressure between the middle and either outside wire.

68. Mixed Systems.—Before leaving the subject of constant-potential alternating-current systems, it will be well to consider the combined use of alternating and direct current as applied to the distribution of light and power. In many large cities, extensive installations on the Edison three-wire system have been made in the past for the operation of both lights and direct-current motors. These were

supplied from stations located as close as possible to the centers to be supplied. As the area to be supplied spread, and as alternating current became more extensively used for power-transmission work, these companies adopted the plan of supplying the existing systems with power from sub-stations fed from one central station, or perhaps from a distant water-power plant.

In order to supply direct current to the distributing system, rotary converters may be used, or, as is done in some cases, alternating-current motors may be used to run direct-current dynamos. Fig. 33 shows the scheme referred to. Alternating current is transmitted from the central station at A, usually by means of the three-phase system, to the substations B or C, where it is stepped down by means of transformers T, T, T. The current may then be sent through rotary converters R and fed into a three-wire system, as shown, or it may be fed to an alternating-current motor M that is coupled to direct-current machines O, O. Very often arc lights are also supplied from these substations by coupling the alternating-current motor to arc-light dynamos and in other cases the rotary converters may be used to feed a street-railway system.

A large amount of lighting is carried out, especially in cities, by using the plan just described. Fig. 34 shows a motor-generator set used for transforming from three-phase alternating to three-wire direct current. The three-phase synchronous motor A receives current from transformers after it has been stepped down from the high-tension line that transmits it from the central station. The motor drives the two direct-current dynamos B and C, which are connected in series and supply current to the three-wire system.

For electric-lighting work, it has been found that the use of a synchronous motor driving direct-current generators gives better results than rotary converters, because the former arrangement maintains a steadier voltage on the direct-current side, a feature of great importance in connection with incandescent lighting. If the voltage supplied

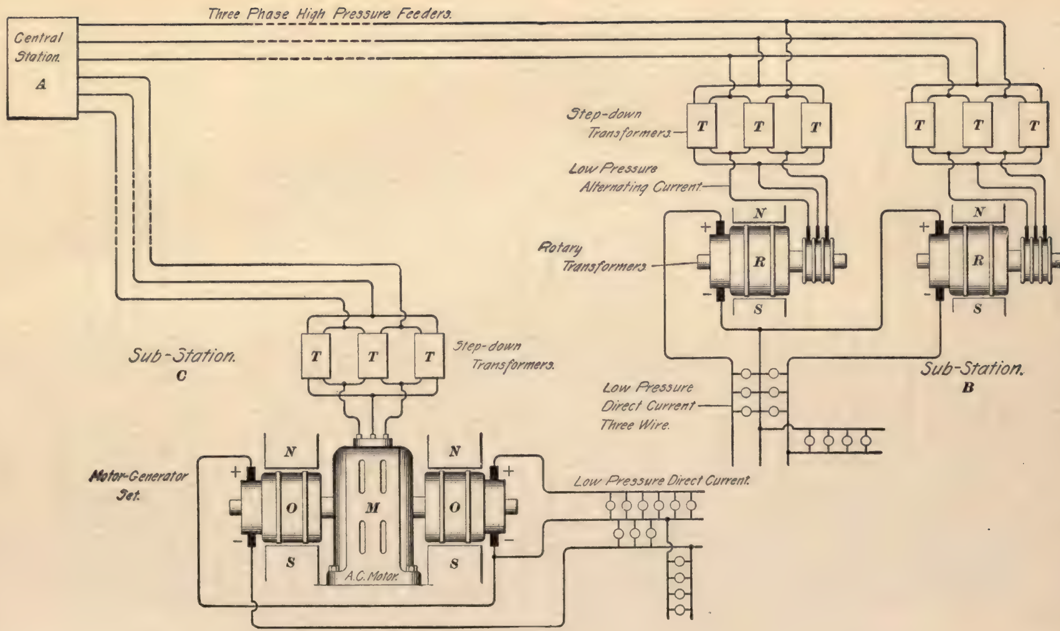

Three Phase High Pressure Feeders.
Central Station.
A
Step-down Transformers.
T
T
T
T
T
T
Low Pressure Alternating Current.
Rotary Transformers.
N
R
S
+
-
Sub-Station.
B
Low Pressure Direct Current Three Wire.
Sub-Station.
C
Step-down Transformers.
T
T
T
Motor-Generator Set.
N
O
S
M
A.C. Motor.
Low Pressure Direct Current.

FIG. 38.

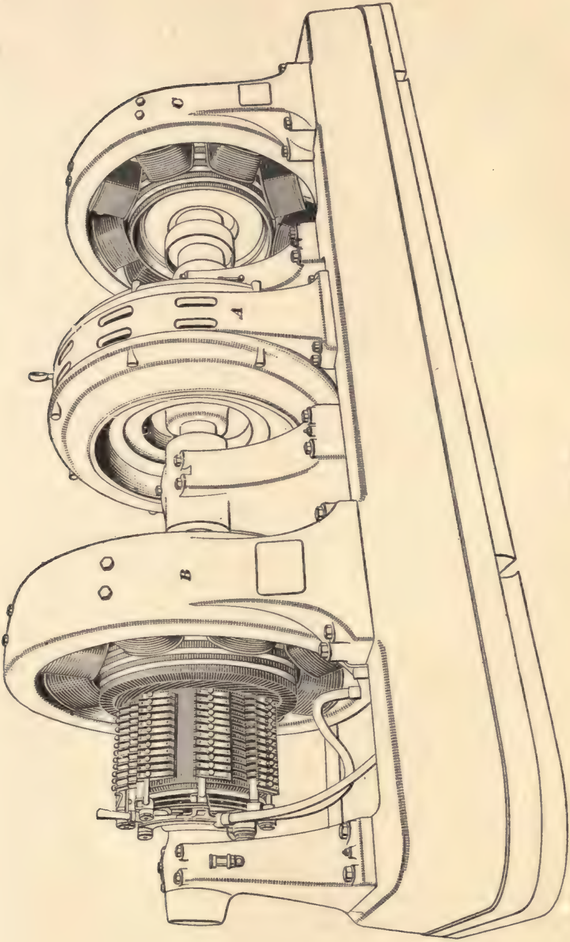


FIG. 34.

to the alternating-current side of a rotary varies, the direct-current voltage will also vary because there is a fixed ratio of transformation between the two voltages. Consequently, all the bad effects of drop in the alternating-current transmission line are felt on the direct-current side, and therefore cause fluctuations in the lamps. If, however, synchronous motors are used to drive separate direct-current machines, the speed of the motor will be constant so long as the speed of the distant dynamo is constant, no matter what may be the fluctuations in the voltage delivered, because the motor is bound to run in synchronism. Since the voltage of the direct-coupled dynamos is constant so long as the speed and field excitation remain the same, it is easy to see that the use of the motor-generator set will give the better voltage regulation.

69. It will be seen from the preceding that the use of constant-potential alternating current of the two-phase or three-phase variety allows a great flexibility in the kind of apparatus operated from one station. If it is necessary to have direct current for any purpose, the transformation is easily effected. In general, where rotary transformers or alternating-current motors are used, it is desirable to have a low frequency, say, about 25 or 40. On the other hand, the frequency should not be below 40 cycles per second if the current is to be used for lighting. A high frequency calls for less expensive transformers, and between all these requirements, which are more or less conflicting, a frequency of 60 has been very generally adopted for systems where the current is used both for light and power. Where power alone is supplied or where the current is used for operating rotary transformers, the frequency may be as low as 25, as in the case of the Niagara transmission plant.

70. Use of Frequency Changers.—In the last article, mention was made of the fact that where rotary converters are extensively used it is customary to use a low-frequency current at 25 or 40 cycles. It sometimes happens

that in connection with such installations a comparatively small amount of alternating current at a higher frequency is required, as the frequency of 25 cycles would be too low to operate arc or incandescent lamps in a satisfactory manner. High-frequency current may be obtained from low-frequency by using a low-frequency motor to drive a high-frequency dynamo or by using a **frequency changer.**

Fig. 35 shows a frequency changer of a type used in connection with lighting work. It consists of a synchronous motor *A* direct connected to an induction motor *B* of special design. Motor *A* is driven by current supplied from the primary lines. The current to be changed is

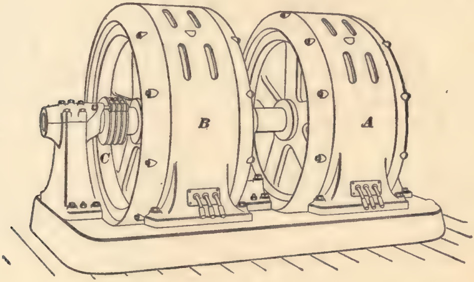


FIG. 35.

led into the stationary field winding of *B*, and the high-frequency current is taken from the armature of *B* by means of the collecting rings *C*. The armature of an induction motor always revolves at a slightly lower speed than the magnetism set up by the field windings, the difference in speed between the armature and the field being known as the **slip.** If the armature were held from turning, the frequency of the currents set up in its windings would be the same as the frequency of the current in the field; in other words, the machine would then be acting like an ordinary transformer. As the motor is allowed to run up

to speed, the frequency of the armature currents becomes slower and slower until the motor runs at a speed only slightly lower than that of the field, and the frequency of the armature currents drops down to from 2 to 5 per cent. of that of the field current, depending on the amount of slip. Now suppose that instead of letting the armature run in the direction it ordinarily would, we drive it in the opposite direction. The effect on the frequency of the currents in the armature is then just the opposite, i. e., the frequency, which is the same as that in the field at standstill, increases as the armature is revolved in the opposite direction by means of motor *A*. If it were run up to its regular speed in the opposite direction, the frequency would be just doubled. If it were driven at half the normal speed in the opposite direction, the frequency would be made one and one-half times as great. For example, if a frequency of 40 were to be raised to 60, the armature would be driven in the opposite direction at half its ordinary speed. Frequency changers of this kind are used, among other places, in connection with the Brooklyn lighting system, and also at Buffalo, where the 25-cycle current from the Niagara plant is changed to 62 cycles for use in connection with lighting work.

ALTERNATING-CURRENT, CONSTANT-CURRENT SYSTEM.

71. This method of distribution is used for operating incandescent street lights in series and has been used quite extensively for that purpose. It allows street lighting to be carried out in connection with a regular constant-potential lighting plant, and such plants are thereby enabled to undertake street lighting with very little expense for station apparatus. Of course, street incandescent lamps could be operated directly from transformers and, in fact, they often are run in this way. As a rule, however, they would be scattered too much to be operated economically in parallel, and hence the series system was developed for this work.

When a number of lamps are connected in series in a circuit, the current in that circuit must be kept at the same value, no matter how many lamps are in operation. The term constant current, as applied to this system, implies, therefore, that the current is maintained at a constant value and not that the current is a direct or continuous one. As mentioned above, such circuits are run from constant-potential alternators, a regulator being used in each circuit to keep the current at a constant value. The series-incandescent system of street lighting is especially useful for small plants, where it would not pay to install separate arc-light dynamos. The system is also used in larger places on streets that are very heavily shaded or in alleys or other places where an arc light is hardly necessary.

72. Fig. 36 shows a series of incandescent lamps *l*, *l* connected across an ordinary constant-potential circuit fed by

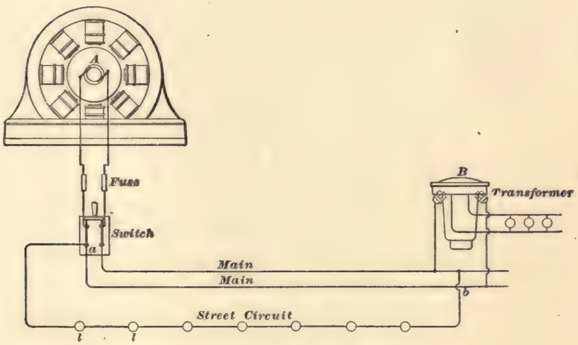


FIG. 36.

the alternator *A*. Suppose, for example, that the pressure generated by the dynamo is 1,000 volts; then if each lamp required, say, 20 volts, 50 lamps would have to be run in

series in order to take up the full voltage of the dynamo. Lamps for use on circuits of this kind are often made for a current of $3\frac{1}{2}$ amperes and a pressure of 20 volts. Such lamps have short, thick filaments, and are generally of the shape shown in Fig. 4. Unfortunately, lamps with short, thick filaments are not nearly as efficient as the ordinary 50-volt or 110-volt lamp with a long, thin filament. For this reason, some of the more recent systems of series-incandescent lighting employ circuits using 50-volt or 100-volt lamps, and use a correspondingly smaller number on each circuit. This is the case with the Westinghouse series system to be described later. So long as none of the lamps burn out, the current in the circuit will remain constant, because the line pressure and the resistance of the lamp circuit are constant. Each lamp must be provided with some means for maintaining the continuity of the circuit in case a lamp breaks down, otherwise all the lamps on the circuit would be extinguished. One of the most common devices for preventing an interruption of the circuit is the **film cut-out,** the principle of which will be understood by referring to Fig. 37. This shows the under side of a lamp base; the flat spring *a* is attached to one terminal and is separated from the other terminal by the film of paper *b*. Ordinarily the pressure between the lamp terminals is equal to the drop through the lamp and is quite small. If, however, the lamp should burn out, the current in the circuit ceases flowing for an instant, thus causing the pressure between the lamp terminals to at once rise to the full pressure of the dynamo, because the current becomes zero and the drop in the line and lamps also becomes zero. This pressure is more than the film can stand, and it is at once punctured, thus allowing *a* to touch the other terminal and maintain the circuit. The film cut-out simply maintains the continuity of the circuit without inserting a resistance of any kind to take the place of the lamp, and the current would, therefore, increase if some means were not adopted for regulating it at the station. There are several

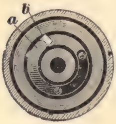


FIG. 37.

arrangements designed for this purpose. Two of the most common are the **lamp-board regulator** and the so-called **C. R. regulator.**

73. The Lamp-Board Regulator.—The principle of this regulator will be understood by referring to Fig. 38. The current is kept at its proper value simply by cutting in a lamp at the station whenever one on the circuit burns out. This board, on which are mounted a number of lamps *l*, *l*, *l*, is placed in the station, and the extra lamps connected in series with the line through a switch *s* and an ammeter *a*. The ammeter indicates when the current is at its proper amount, and if a lamp on the line goes out, the reading at once increases. By moving the handle of the switch *s*, any number of lamps desired may be cut in and the current maintained at its proper value until the lineman is able to go around and replace the broken lamps. The figure is only intended to show the general principle of the lamp board; the actual arrangement of the parts varies in different cases.

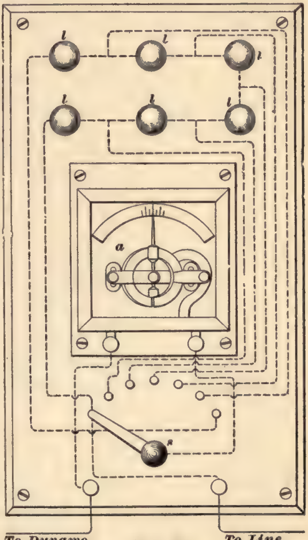


FIG. 38.

74. The C. R. Regulator.—This regulator was brought out by the General Electric Company to replace the old lamp-board method of regulation. In many cases it is desirable to have some kind of regulator that will not only

compensate for any lamps that may burn out, but that will also allow a wide variation in the voltage applied to the circuit. For example, we might wish to run a circuit having 40 20-volt lamps from a 1,000-volt alternator. The series of lamps would only require $40 \times 20 = 800$ volts, and if the lamp board were used, 10 lamps would have to be inserted in the station to take up the extra 200 volts, neglecting the drop in the line. This would be an expensive and wasteful method.

The C. R. regulator is simply a special kind of transformer that is so made that its secondary voltage may be added to or subtracted from that of the dynamo. The operation of this regulator will be understood by referring to Fig. 39. Two coils *A B* and *C D* are wound on a laminated iron core. The coil *C D* is divided into a number of sections, and connections are brought out to the contact

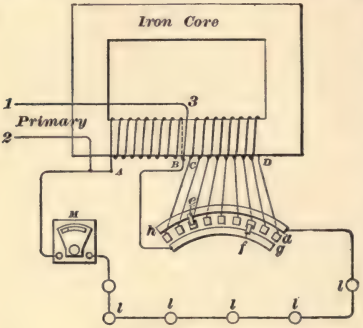


FIG. 39.

blocks *a*; *h* and *g* are two contact strips in the form of circular arcs, *h* being connected to one end of the lamp circuit and *g* to one end of the coil *B*, which is also connected to one of the primary lines. The other end of the primary coil is connected to the circuit and to the other primary wire, as shown at *A*. An ammeter is also included in the circuit to show when the current is at its proper value. The contact pieces *e*, *f* make contact between the circular arcs and the coil terminal pieces *a*, and are so arranged that when a wheel is turned they move towards each other or away from each other, as the case may be. They are also arranged so that they may move past each other

Suppose that both *e* and *f* rest on the same block in the center of the dial; then, the current flows from the line through the path *1–3–B–g–f–e–h–l–l–l–M–2*, and the pressure applied to the lamp circuit is the same as that supplied by the alternator. A current will also flow through *A B*, because this coil is connected directly across the line, just like the primary coil of a transformer. This current will set up an alternating magnetism around the iron core and an electromotive force in the coil *C D*. If now we connect any of the turns of *C D* in series with the lamp circuit, the pressure applied to the lamps will be greater or less than the dynamo pressure, depending on whether the E. M. F. induced in the part of *C D* cut in aids or is opposed to the E. M. F. of the dynamo. Suppose the regulating wheel to be moved so that the contact pieces are in the position shown; the current will flow through that part of the coil *C D* included between the contacts *e*, *f*, and we will suppose that the connections are such that the E. M. F. of this portion of the coil is added to the line. If the handle is turned the other way, so that the sliding pieces *e* and *f* move past each other and thus exchange places, it is readily seen that the effect is to make the current pass through the portion of the coil between *e* and *f* in the opposite direction to what it did before; hence, with the contacts in this latter position, the line E. M. F. will be diminished by the E. M. F. induced in the portion of the coil cut in. It follows, then, that with this arrangement, the E. M. F. applied to the line may be raised or lowered by the E. M. F. supplied to the coil *C D*. For example, in a regulator designed for a circuit of 1,100 volts, the adjustable coil is wound for 230 volts and is divided into 23 sections of 10 volts each. The voltage on the line can, therefore, be varied from 1,100 − 230 to 1,100 + 230, i. e., from 870 to 1,330 volts. This allows quite a wide variation in the number of lamps that can be operated on a circuit and gives at the same time a ready means of adjusting the current in case a few lamps happen to burn out.

Fig. 40 shows the general appearance of one of these regulators. The regulating dial is seen in the center and is so arranged that when the wheel is turned, one arm moves in one direction and the other arm in the opposite direction. The switch at the top of the board serves to disconnect the regulator from the circuit and dynamo.

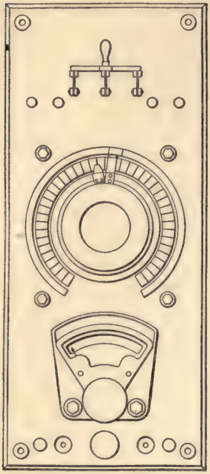


FIG. 40.

75. Westinghouse Constant-Current Incandescent System.—The series-incandescent street-lighting devices used by the Westinghouse Company are considerably different from the two previously described, in regard to the method of compensating for burned-out lamps. Ordinary 50-volt or 100-volt lamps are used. For example, on a 1,000-volt circuit, 20 50-volt or 10 100-volt lamps would be connected in series. These are preferable to the low-voltage 20-volt lamps, because they are more efficient. Moreover, the ordinary 50-volt or 100-volt lamps are cheaper. The

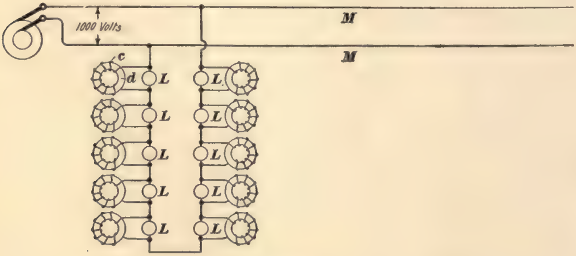


FIG. 41.

operation of the Westinghouse device will be understood by referring to Fig. 41. L, L, L represent a series of

ten 100-volt lamps connected across the 1,000-volt mains *M*. Across the terminals of each lamp a coil *c*, wound on a laminated iron core *d*, is connected so that the coil is in shunt with the lamp under ordinary working conditions. If a lamp should break, the current must then pass through the coil. As long as the lamp is unbroken, but a very small current passes through the shunt coil; just enough current will flow to magnetize the coil sufficiently to generate a counter E. M. F. of 100 volts. When the lamp burns out, the whole current passes through the shunt coil, but as the iron in the core is worked at a point near saturation, the counter E. M. F. rises but slightly over 100 volts, although the current through the coil is very much greater than it was before the lamp broke. The coil, therefore, takes the place of the lamp and introduces into the circuit a counter E. M. F. of slightly over 100 volts to take the place of the lamp. The current remains about the same and the life of the remaining lamps is not endangered. If as many as four or five lamps are out at once, the remaining lamps become somewhat dim on account of the fact that each shunt coil introduces a little higher counter E. M. F. than the amount of the drop through the lamp that it replaces. All that is necessary to restore the circuit to its normal condition is to replace the burned-out lamps. This system has the advantage that it is automatic in its action, requiring no attention other than the replacing of old or burned-out lamps. It also has the advantage that it is not necessary to bring the circuit to the station. One end of the circuit may be attached to the main at any convenient point and the other end attached to the other main, the only essential being that the two ends shall connect to the two sides of the circuit. It has the disadvantage that if a short circuit occurs on the line,

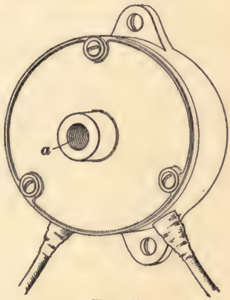


FIG. 42.

a number of the shunt coils are liable to be burned out. The shunt coils are mounted in cast-iron boxes, which also serve for the base of the bracket supporting the lamp. Fig. 42 shows the shunt-coil box. The hole *a* is tapped

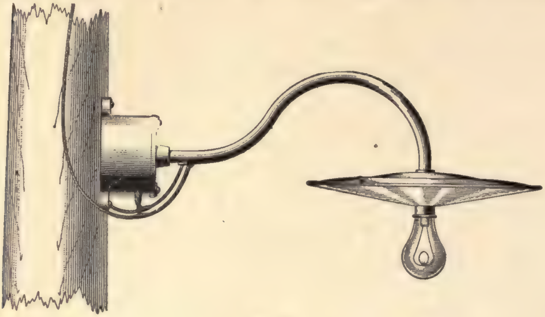


FIG. 43.

to receive the gas-pipe bracket, as shown in Fig. 43. Street incandescent lamps are usually provided with white enameled reflectors and are mounted about 10 to 15 feet above the ground.

SUMMARY.

76. The methods of distribution described above represent those commonly used in practice, and it will be seen that the electrical engineer has a large number of methods from which to choose when installing a plant. Just which one is best suited to any particular case will be decided largely by the amount of the power and the distance over which it is to be transmitted. The use of multiphase systems is becoming very popular, and they are now very common whenever the power is to be transmitted for any considerable distance. Either the two-phase or three-phase systems are suitable for this work, and there is little choice between them. Direct current, using either the two-wire or three-wire system, will, no doubt, continue to be used very

extensively for isolated plants or for supplying light to compact and thickly settled districts; it is simpler for this purpose than alternating current, and there is no need of using a high pressure under such circumstances, as the saving in copper would be more than offset by the additional cost of transformers.

LINE CALCULATIONS.

TWO-WIRE AND THREE-WIRE, DIRECT-CURRENT SYSTEMS.

77. The methods for calculating the size of wire required to transmit a given current over a given distance with a certain allowable drop are the same as those used for the calculation of power-transmission lines, though sometimes the formulas are put in a slightly different form so as to be more directly applicable to the subject of electric lighting.

78. The formula that is most generally applicable is the following:

$$A = \frac{21.6 \times D \times C}{e}, \qquad \textbf{(5.)}$$

where A = required area of cross-section of wire in circular mils;
D = distance in feet (one way) to point where current is distributed;
C = current in amperes transmitted;
e = drop in volts.

In making line calculations in connection with electric lighting, some judgment must be exercised in choosing the value of the distance D. This is not the distance to the first lamp supplied or the distance to the farthest lamp, but the distance to the center of distribution; in other words, the distance to the point at which we might imagine all the lamps to be grouped. The product of the distance D to the center of distribution and the current C is often spoken of

as the ampere-feet of the circuit; hence, we may write the rule as follows:

Rule.—*The area in circular mils required for a two-wire circuit is found by multiplying the ampere-feet by 21.6 and dividing by the drop in volts.*

79. Center of Distribution.—The distance D to the center of distribution will be best understood by taking a few cases illustrating the point. Consider a number of lamps l, l, Fig. 44, arranged as shown and fed by the dynamo A. The distance from the dynamo to the first lamp is 1,000 feet, and the lamps are spaced out over a distance of 100 feet. The whole of the current would have to

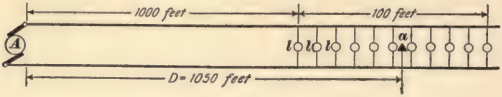


FIG. 44.

be transmitted through the first 1,000 feet, but from that point it would gradually fall off. We may then take the point a as the center of distribution, because the load is about equally distributed on each side of this point, and the distance D used in the formula would be 1,050 feet.

Take the case shown in Fig. 45, where the lamps are spaced evenly all the way along the line. In this case, the center of

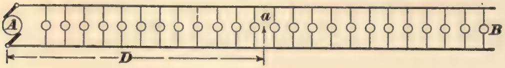


FIG. 45.

distribution a may be taken as at the middle, and hence the distance D is only one-half the length of the line from A to B. The exact location of the center of distribution becomes more difficult to determine when the load is unevenly spaced or distributed, but in most cases it can be located close enough for practical purposes by laying out the system and noting carefully the loads on the different circuits.

80. Current Estimation.—The current can be readily determined when the nature of the load is known. The general practice is to allow $\frac{1}{2}$ ampere for each 16-candlepower lamp and 1 ampere for a 32-candlepower lamp on 110-volt circuits. It might be well to mention at this point that some prefer to make calculations for lighting circuits by using *lamp-feet* instead of ampere-feet. The number of **lamp-feet** is the product of the number of 16-candlepower lamps to be supplied and the distance to the center of distribution. When this term is used, it always implies the use of 16-candlepower lamps; if any 32-candlepower lamps are operated, each lamp must be counted as two 16-candlepower, etc. If lamp-feet are used, the formula becomes

$$A = \frac{10.8 \times D \times N}{e}, \qquad \textbf{(6.)}$$

where $A =$ area in circular mils;
$D =$ distance in feet one way to center of distribution;
$N =$ number of lamps (expressed in terms of 16-candlepower lamps);
$e =$ drop in volts.

Rule.—*To determine the area of cross-section for a two-wire 110-volt circuit, multiply the lamp-feet by 10.8 and divide by the drop in volts.*

81. This rule is here given because it is frequently used Formula **5** is, however, much to be preferred, because formula **6** assumes that each lamp takes $\frac{1}{2}$ ampere, and this may or may not be the case. Formula **5** is applicable to any case because the current is used in it, and this current is determined from a knowledge of the devices to be operated. The use of these formulas will be understood from the following examples, applying them to the calculations of lines for an ordinary two-wire lighting system. We will first take the simple case shown in Fig. 44.

EXAMPLE 1.—A dynamo A, Fig. 44, delivers current at 110 volts to 50 lamps distributed as shown about a as a center. The drop must not exceed 10 volts. Find the size of wire required.

SOLUTION.—The distance to the center of distribution is here 1,050 feet, as already explained. The current will be 25 amperes, because each lamp will take $\frac{1}{2}$ ampere. Using formula **5**, we have

$$A = \frac{21.6 \times 1{,}050 \times 25}{10} = 56{,}700 \text{ cir. mils. Ans.}$$

A No. 3 B. & S. wire would likely be used.

EXAMPLE 2.—A dynamo A, Fig. 46, supplies current through the feeders b, c to the feeding-in point a. From this point lamps are supplied by means of the mains d, e and f, g. The number of 16-candle-power lamps and the various distances are shown in the figure. The total drop in voltage from the dynamo to the last lamps must not

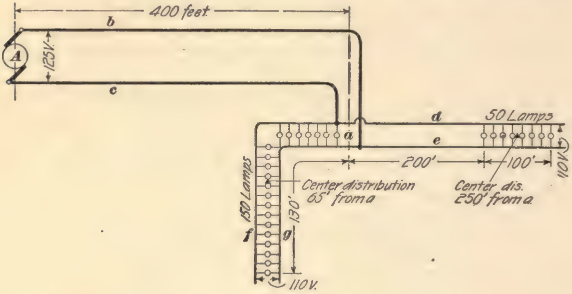


FIG. 46.

exceed 15 volts, of which 13 volts is to be in the feeders and 2 volts in the mains; required, (a) the cross-section and gauge number of the feeders b, c; (b) the cross-section and nearest gauge number of the mains d, e; (c) the cross-section and nearest gauge number of the mains f, g.

SOLUTION.— 150 lamps will require 75 amperes.
50 lamps will require 25 amperes.

Total current 100 amperes.

(a) We are allowed a drop of 13 volts in the feeders and a drop of 2 volts in the mains. No current is taken from the feeders at any intermediate point; hence, the distance D from the dynamo to the center of distribution a will be taken the same as the actual distance, i. e., 400 feet. Using formula **5**, we have, then, for the feeders

$$A = \frac{21.6 \times 400 \times 100}{13} = 66{,}461 \text{ cir. mils.}$$

This would call for a No. 2 B. & S. wire. Ans.

(*b*) The current in the mains *d*, *e* will be 25 amperes. The distance from *a* to the center of distribution will be $200 + \frac{100}{2} = 250$ feet, because the lamps are spaced evenly along the last 100 feet. The drop in the mains is not to exceed 2 volts; hence, we have

$$A = \frac{21.6 \times 250 \times 25}{2} = 67{,}500 \text{ cir. mils.} \quad \text{Ans.}$$

This also would call for a No. 2 B. & S. wire. No. 2 B. & S. wire is a little smaller than the cross-section called for, but it would probably be used, as the increased drop caused by doing so would be very small.

(*c*) The current supplied through mains *f*, *g* is 75 amperes. Here the load is uniformly distributed along the mains, and the distance to the center of distribution is $\frac{130}{2} = 65$ feet. The drop is 2 volts. We have, then,

$$A = \frac{21.6 \times 65 \times 75}{2} = 52{,}650 \text{ cir. mils.}$$

This would call for a No. 3 B. & S. wire. Ans.

It will be noticed in this example that although the mains carry a smaller current over a shorter distance than the feeders, they work out about the same size. This is because of the large drop allowed in the feeders compared with that in the mains.

EXAMPLE 3.—Fig. 47 shows a three-wire distributing system. The dynamos *A*, *B* supply current through feeders to the junction box *J*. From this point mains are carried to the buildings where light is to be supplied. In this case, the conductors marked mains are sometimes called subfeeders, because they are really branches of the main feeder and no branches are taken off between the junction box and the end of these lines. In this case, the total drop from the dynamo to the lamps is not to exceed 10 per cent. of the lamp voltage, and the pressure at the lamps is to be 110 volts. (*a*) Calculate the size of the feeders *C*. (*b*) Calculate the size of the mains *D*. (*c*) Calculate the size of the mains *E*. The calculation of the size of wires required for the house wiring will not be taken up here, as it belongs to interior wiring and we are only concerned for the present with the outside distributing wires. The pressure at the dynamo will be $110 + 110 \times .1 = 121$ volts. Of the total drop of 10 per cent. we will allow 1.5 per cent. in the house wiring, 3.5 per cent. in the mains, and the remaining 5 per cent. in the feeders, as indicated in the figure.

SOLUTION.—In calculating the size of the conductors, we will consider the system as a two-wire system, the pressure between the two outside wires at the lamps being $2 \times 110 = 220$ volts and at the dynamo $2 \times 121 = 242$ volts. We will obtain the size of the outside wires, and a neutral wire one-half the size of the outside wires should be amply sufficient. The total current supplied may be obtained as follows:

(*a*) Each pair of lamps on a 220-volt three-wire system requires $\frac{1}{4}$ ampere; hence, current in line D will be $\frac{100}{4} = 25$ amperes. Current in E will be $\frac{400}{4} = 100$ amperes. Total current in the feeders C will be 125 amperes. The total drop between the outside wires is $242 - 220 = 22$ volts. The drop in the main feeders is to be 5 per cent. of the lamp voltage, or $220 \times .05 = 11$, or 5.5 volts on each side. The distance to the center of distribution is 700 feet; hence,

$$A = \frac{21.6 \times 700 \times 125}{11} = 171{,}818 \text{ cir. mils. Ans.}$$

This would call for a No. 000 B. & S. wire for the outside wires from the dynamo up to the point J. The neutral wire could be made about No. 1.

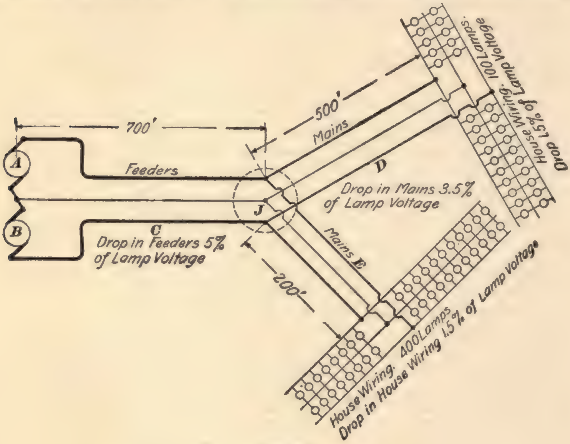


FIG. 47.

(*b*) The drop in mains D or E will be $220 \times .035 = 7.7$ volts. The area of mains D will be

$$A = \frac{21.6 \times 500 \times 25}{7.7} = 35{,}065 \text{ cir. mils. Ans.}$$

This would require a No. 5 wire, and a No. 8 or 9 would be sufficient for the neutral.

(*c*) The area of mains E will be

$$A = \frac{21.6 \times 200 \times 100}{7.7} = 56{,}104 \text{ cir. mils, nearly. Ans.}$$

A No. 3 B. & S. wire would probably be used for the outside wires and a No. 6 for the neutral.

CALCULATIONS FOR ALTERNATING-CURRENT LINES.

82. A load that consists wholly of lamps possesses very little self-induction, and for ordinary lighting systems, where the distances are short, it is usual to make the calculations for lines carrying alternating current in the same way as already described for the direct-current system. This assumes the power factor to be 1, which is not exactly true. If greater accuracy is required, formulas taking into consideration the power factor should be used. After the primary current has been determined and the distance to the center of distribution is known, the size of the primary line wire may be worked out. The power supplied over the line must be slightly greater than that supplied to the lamps, on account of the loss in the transformers. This loss will depend, of course, on the efficiency of the transformer; some of the older styles had a low efficiency, but very little power is wasted in transformers of modern make. Table III gives the average efficiency at full load, as attained by good transformers.

TABLE III.

EFFICIENCY OF TRANSFORMERS.

Output. Watts.	Efficiency. Per cent.	Output. Watts.	Efficiency. Per cent.
1,000	94.8	7,000	96.80
2,000	95.7	8,000	96.85
3,000	96.2	9,000	96.90
4,000	96.4	10,000	96.95
5,000	96.6	15,000	97.20
6,000	96.7		

83. In order to illustrate the calculation of primary mains, we will consider the case shown in Fig. 48.

EXAMPLE.—Current is supplied to the transformers T by means of the primary mains A, B. The voltage at the lamps is to be 104 volts

(a common value used in connection with alternating-current lighting work). A total of 1,000 16-candlepower lamps is to be operated from the secondaries. The voltage at the transformer is to be 2,000 volts at full load and the drop in the primary mains 200 volts, thus making the

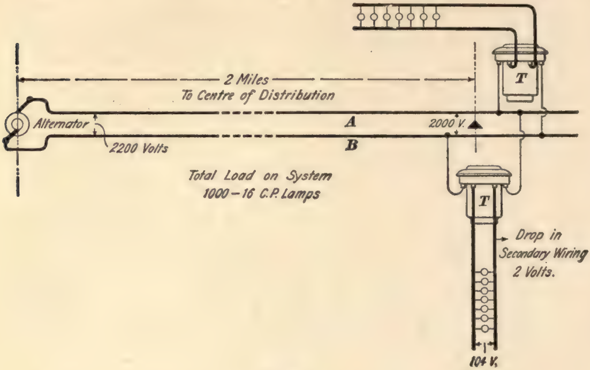


FIG. 48.

voltage at the alternator 2,200 volts at full load. The loss in the secondary wiring at full load must not exceed 2 volts, and the lamps require 3.5 watts per candlepower. The average efficiency of the transformers may be taken at 96 per cent. Required the cross-section of the primary wires.

SOLUTION.—Each lamp requires $16 \times 3.5 = 56$ watts, and 1,000 lamps would call for 56,000 watts in the secondary circuit at the lamps. The total secondary current would be $\frac{56000}{104}$ amperes, and since there is a drop of 2 volts in the secondary wiring, the number of watts lost will be $\frac{56000}{104} \times 2$, and the total watts delivered by the secondary must be $56{,}000 + \frac{56000}{104} \times 2 = 57{,}077$, nearly. The watts delivered to the primaries would be $\frac{57{,}077}{.96} = 59{,}455$, and since the primary voltage of the transformers is 2,000, the primary current will be $\frac{59455}{2000} = 29.73$ amperes, nearly. Having determined the primary current, we can now calculate the size of the line. The distance in this case is 2 miles, or 10,560 feet, and the drop 200 volts. We may now use formula **5**, considering the problem the same as for a continuous-current circuit.

$$A = \frac{21.6 \times 10{,}560 \times 29.73}{200} = 33{,}906, \text{ approximately. Ans.}$$

This would call for a No. 5 B. & S. wire.

84. For rough calculations of the primary current on 1,000-volt and 2,000-volt primary mains, the following allowance per lamp may be used:

TABLE IV.

CURRENT ALLOWANCE PER LAMP.

Candlepower of Lamp.	1,000 Volts Primary Pressure. Current per Lamp.	2,000 Volts Primary Pressure. Current per Lamp.
10	.035	.0175
16	.050	.0250
32	.100	.0500
50	.150	.0750

For example, if 800 16-candlepower lamps were operated on a 2,000-volt circuit, the primary current would be about $800 \times .025 = 20$ amperes. This, of course, does not give the current exactly, because to obtain this the efficiency of the transformers and the lamps should be known, but it affords a ready means of getting at the current approximately when preliminary calculations are being made. In many cases, the more refined calculations would not change the size of the wire in any event, because the wire selected must be taken as one of the standard sizes, and this in most cases is not the same as the calculated size.

85. In case the lamps are operated on two-phase or three-phase systems, the watts to be supplied by the alternator can easily be obtained when the watts per lamp and the efficiency of the transformers are known. After the watts have been determined, the formulas given in *Electric Transmission*, Part 1, may be used to calculate the size of the wire.

EXAMPLE.— 1,000 16-candlepower, 60-watt lamps are to be operated on a three-phase system at a point 16,000 feet from the station. The voltage at the transformers is to be 2,000, and 10 per cent. of the power delivered is to be allowed as loss in the line. The transformer efficiency is 96 per cent., and 2 per cent. of the power delivered at the lamps is lost in the secondary wiring. Find the necessary cross-section of the line wires.

SOLUTION.—Power supplied to lamps $= 1,000 \times 60 = 60,000$ watts. Power delivered by secondaries $= 60,000 + .02 \times 60,000 = 61,200$. Power supplied to transformers from primary lines $= \frac{61,200}{.96} = 63,750$ watts.

Referring to *Electric Transmission*, Part 1, we find that the circular mils are given by the formula

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t.$$

In this case, $D = 16,000$; $E_2 = 2,000$; $P = 10$. Since this is to be a three-phase system and the load consists wholly of lights, the constant t may be taken as 1,200.

Hence,

$$\text{Circular mils} = \frac{16,000 \times 63,750}{10 \times 2,000 \times 2,000} \times 1,200 = 30,600. \quad \text{Ans.}$$

This is between a No. 5 and a No. 6 B. & S. wire. The No. 5 wire would most likely be used.

86. When the total watts to be delivered are known, the current in the line and the drop in voltage may be estimated by means of the formulas given in *Electric Transmission*, Part 1. The percentage drop in voltage may be considerably greater than the percentage loss in power if the lines are long and spread a considerable distance apart, because under such circumstances the self-induction of the lines would have considerable effect. It is customary when making calculations with regard to ordinary single-phase lighting circuits that are not of great length to use the rules given for direct current. This is especially true with regard to the secondary distributing system, and in nearly all cases will give results sufficiently accurate for practical purposes.

THE LIGHTING STATION.

87. The design of the central station for an electric-lighting plant involves a great many considerations that depend on the system of distribution adopted. The choice of the system itself, as to whether the direct or alternating current should be used, is dependent on the area of the territory to be lighted and on the distance between the centers of generation and distribution. Thus, for small districts in which the lighting is dense and in which the central station can be placed approximately in the center of the area illuminated, the two-wire, direct-current, low-pressure system is the one most suitable. It has been found, however, that such a system is no longer economical when the mean length of the feeders becomes greater than 300 yards.

By the Edison three-wire system, the distribution of direct-current, low-pressure supply may be economically conducted for a feeder length of from one-half to three-quarters of a mile. The five-wire system allows of a mean feeder length of one mile. Beyond this distance direct-current systems are too costly, and, therefore, the alternating-current system is used.

88. The Location of the Central Station. — Since nearly all incandescent-lighting stations use the constant-potential or parallel system of distribution, the location of the station with reference to the district to be supplied is of the highest importance and should never be decided on until all conditions entering into the problem have been carefully weighed; for when this system is used the question of conducting heavy currents makes the cost of the conductor a figure that must be kept as low as possible, and this can only be attained by making all distances as short as possible. This would mean that the central station should be placed in the center of the system to be served. Very often it is found that, owing to the questions of coal and water supply, the price of real estate, or other local conditions, the central station cannot be placed in the center

of the system, and that the loss in conductor copper is offset by other advantages. These are points that the designing engineer considers after studying the map of the area to be served and the estimates of the probable supply.

In general, however, it will be observed that the central station in parallel distribution forms very nearly the electrical center of gravity of the system. The present tendency in large cities seems to be towards the consolidation of the generating plant in one large central station located at some point where the fuel and water supply is good. This is the natural outcome of high-tension transmission. These stations are provided with alternators of large output that supply current at high pressure to various substations located near the points of distribution. By utilizing this high-pressure transmission scheme, it becomes unnecessary to have the plant located near the point where the current is used. Such an arrangement involves more complication than where the current is supplied directly from the generating station, but for large cities it is, nevertheless, found to be advantageous.

89. The Boilers.—The greatest demand for current from a central station supplying lighting circuits occurs at stated hours, during which time the boilers are usually called upon for their full steam capacity. Before and after this time the demand for current is very much less, and the boilers are, therefore, not often worked to their full capacity. Unless they are used continuously, it is evident that the lighting and firing up of the several boilers for only short periods during the evening produces an immense waste of heat from radiation and conduction, which takes place as they cool down after having been thrown out of use. Such losses are, of course, increased when there are larger masses of brickwork in direct contact with the fuel which must be heated up. For this reason, internally fired boilers, such as the marine boilers or the Lancashire type, are often used, though the latter has the objectionable feature of requiring much floor space. Owing to this cause, water-tube boilers,

of which the well-known Babcock & Wilcox is a good example, are very generally used in electric-lighting stations.

90. The Engines.—In the selection of engines, the choice lies between direct-coupled engines and those driving dynamos by belting or rope gear.

The engine built for direct coupling to dynamos must necessarily have the speed required to run the dynamo. This speed is a relatively high one for engines, even where the dynamo is very large, and until quite recently such engines were not numerous. At present, however, high-speed engines of high grade are much used, and the modern central station is mainly equipped with direct-coupled machines. These are particularly adapted to stations where space is limited. Where this is not the case, many plants drive their dynamos in groups, either from the engine fly-wheel or by means of belting.

DYNAMOS FOR INCANDESCENT LIGHTING.

91. The type of dynamo used for operating a lighting system will depend on the method of distribution adopted. The construction of the dynamo will also depend to some extent on the method used for driving it; i. e., on whether it is driven by means of a belt or coupled directly to the steam engine or waterwheel. We will consider, briefly, a few of the different types used in order to point out some of their distinguishing features.

DIRECT-CURRENT DYNAMOS.

92. Belt-Driven Dynamos.—Dynamos used for operating incandescent lamps on the two-wire or three-wire systems are almost invariably compound-wound. Shunt-wound machines were used some years ago for this purpose, but the compound-wound machine is much better, since it keeps the voltage at the right value automatically. Usually the machines are overcompounded, so as to give a rise in

voltage from no load to full load corresponding to the drop in the line, and thus keeping the pressure at the lamps con-

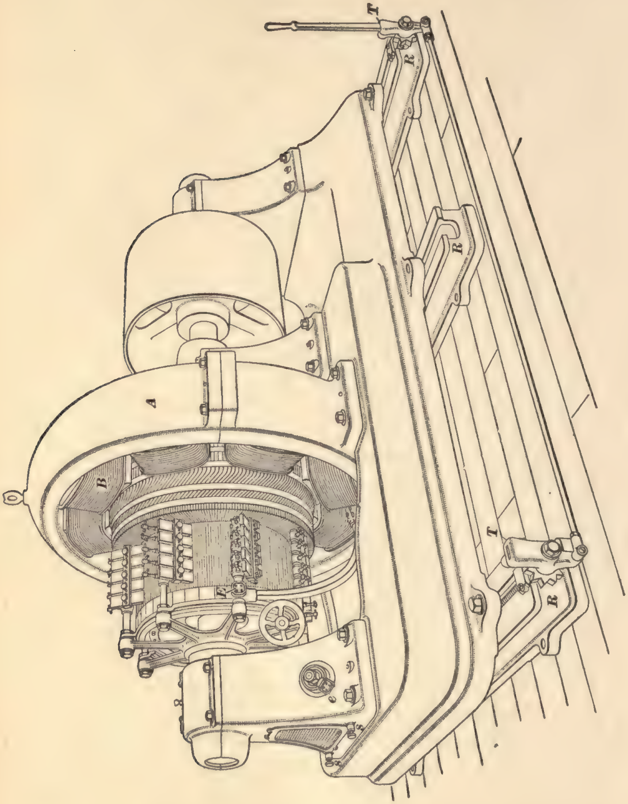


Fig. 49.

stant. Modern dynamos used for this purpose are nearly always of the multipolar type. Two-pole machines were

formerly much used, but these have given place to the multipolar type. All the dynamos used for any kind of work may be divided into two classes, according to the method used for driving them, i. e., **belt driven** and **direct connected.**

Fig. 49 shows a Wood eight-pole compound-wound dynamo as used for lighting on a 110-volt, two-wire system, or 110–220-volt, three-wire system. This machine is mounted on rails *R*, so that the tension of the belt may be adjusted by sliding the machine by means of the ratchets *T*, *T*. The magnet yoke *A* is circular and is provided with eight inwardly projecting poles, each of which is provided with a field spool *B*. Each of these spools is provided with two windings: a shunt winding, consisting of comparatively fine wire, and a series winding, usually of copper strip or heavy wire, capable of carrying the whole current furnished by the machine. One terminal of the machine is shown at *e*, and the other is on the opposite side of the pedestal. From these two terminals the positive and negative leads are carried to the switchboard. The connections for the shunt winding and the shunt-field rheostat are made by means of the small terminals *s*, *s*. When two or more machines are run in multiple, a third main connection is led from the terminal *E* to the equalizing bar on the switchboard. The machine shown has a capacity of 260 kilowatts, runs at 500 revolutions per minute, and weighs a little over 9 tons complete. Belt-driven machines are smaller and cheaper for the same output than direct-connected machines, because they run at a higher speed. Notwithstanding this fact, the direct-connected type is becoming very popular, especially in places where economy of space and compact arrangement are desired.

93. Direct-Connected Dynamos.—By using direct-driven machines, all wear and tear on belts is avoided and a large saving in space effected. Fig. 50 shows a compound-wound dynamo made by the Fort Wayne Electric Works direct connected to a high-speed engine, and is a

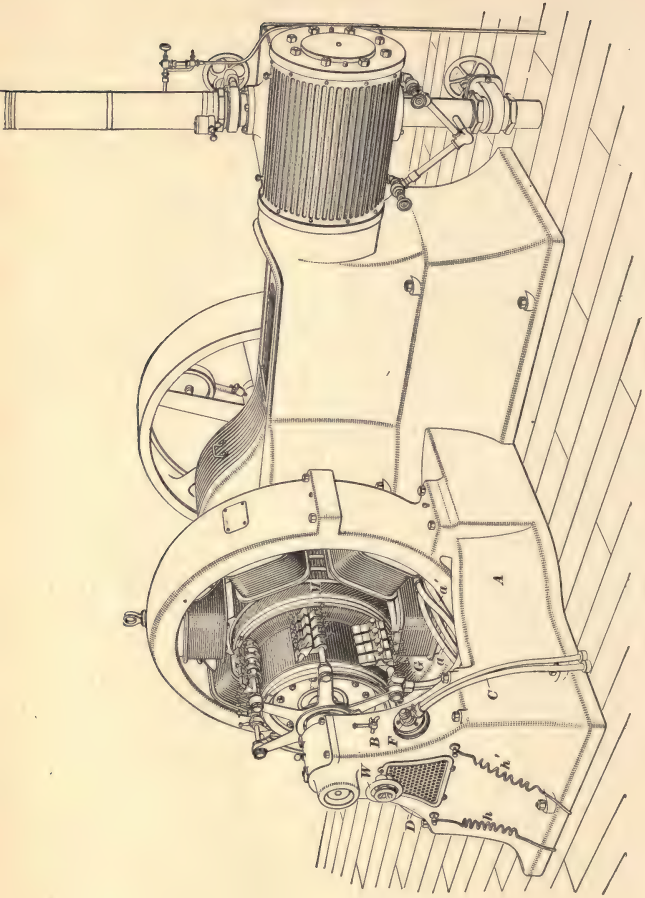


Fig. 50.

typical example of a multipolar direct-driven set. Such a combination is largely used for isolated plants and also for central stations of moderate size. For larger stations it is customary to use slow-speed engines of the Corliss type direct connected to large multipolar dynamos. The dynamo, Fig. 50, is mounted upon an extension bedplate *A* provided with an outboard bearing *B*. This machine is compound-wound, *a*, *a'* being the leads connecting to the terminals of the series coils; *C* and *D* are the mains running to the switchboard; the leads from the brushes are attached to the connection boards, one of which is shown at *F*. The terminal for the equalizing wire is shown at *G*. The small leads *h*, *h'* are connected to the shunt winding and are led to the switchboard so that the field rheostat may be connected in series with the shunt field. The hand wheels shown at *W* are for adjusting the brushes to the non-sparking point and clamping them in position. Nearly all modern dynamos use carbon brushes, except, perhaps, a few machines where the voltage is low and the current correspondingly large. In order to use carbon brushes without overheating at the commutator, it is necessary to allow ample contact surface between brushes and commutator. Usually about 1 square inch of brush contact surface is necessary for every 30 to 40 amperes collected, and in the case of low-tension incandescent-lighting dynamos this calls for a large commutator. Notwithstanding the fact that carbon brushes require a much larger and more expensive commutator than copper brushes, they operate so much better that the increased first cost is warranted. The carbon brushes run with much less sparking and do not cut the commutator, as copper brushes are apt to do, unless they are very carefully looked after. Most incandescent dynamos have bar-wound armatures, i. e., the conductors on the armatures are in the shape of copper bars rather than wires, because a large cross-section of conductor is necessary in order to carry the current. The ends of these bars leading to the commutator are seen at *M*, Fig. 50. The machine here shown has a capacity of 75 kilowatts and runs

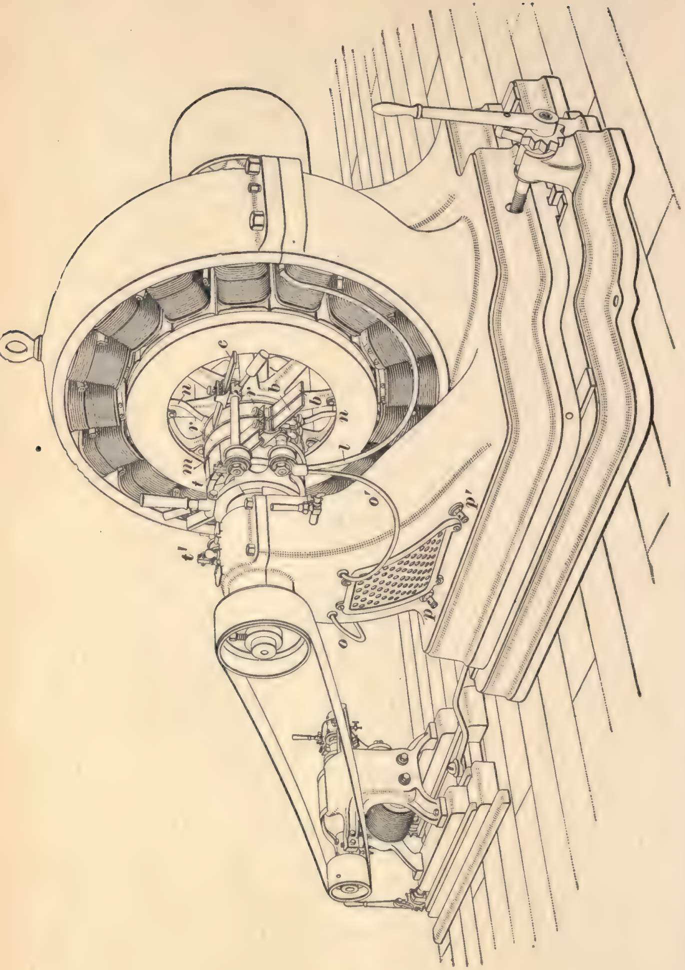


FIG. 51.

at a speed of 275 revolutions per minute. The speed of the larger sizes of direct-connected machine is correspondingly lower, and in case they are direct connected to large, slow-speed Corliss engines, the speed is usually from 75 to 100 revolutions per minute.

ALTERNATING-CURRENT DYNAMOS.

94. Alternators may be constructed with either the armature or field as the revolving member, or they may be made without any revolving wire whatever, the only revolving part being a mass of iron, called an **inductor.** We may have, then, a comparatively large number of different types of alternators to choose from as compared with direct-current machines. When alternating current first came into use for lighting work, machines with revolving armature and stationary field were the only kind used, and these machines were almost invariably belt driven. The frequency employed was usually from 125 to 133 cycles per second, and the machines were often provided with a compound winding supplied through a rectifier. Practically all the alternators in use are wound to give a constant potential. The shunt winding of the ordinary compound-wound continuous-current dynamo is replaced by a separately excited winding, which is supplied from a small direct-current exciter. Again, the variety of alternators is increased by the various number of phases that are in common use.

95. Belt-Driven Alternators.—Fig. 51 shows a typical belt-driven alternator as used for lighting work. This particular machine is of the Wood type made by the Fort Wayne Electric Works, and it illustrates the general characteristics of a type of machine that has been and still is largely used for incandescent-lighting work. The Westinghouse and General Electric alternators of this class are very similar in general appearance to the one shown. This is a single-phase machine of 150 kilowatts capacity delivering

current at 60 cycles per second. The alternator is provided with only two collector rings *r*, *r* because it generates single-phase current. Each ring is provided with a brush *c*. The rectifier is shown at *m*, and by means of it the current sent through the series field winding is made unidirectional; *b*, *b* is a pair of the rectifier brushes and there is a similar pair, not shown, on the opposite side of the rectifier. One of the leads connecting to the series field is shown at *l*, and there is a similar one on the other side of the machine. The terminals of the armature winding leading to the collector rings and rectifier are shown at *n*, *n*. The terminals of the machine are *t*, *t'*, and from these the main wires are led to the switchboard. The two leads *o*, *o'* lead from the terminals of the series coil to the shunt used in connection with the compound coils. This shunt is housed in the bearing pedestal. The exciter is here shown belted to a pulley on the end of the alternator armature shaft. In many cases the exciter is driven separately. The binding posts *p*, *p'* are the terminals of the separately excited field coils. The whole machine is mounted on rails so that the tension on the belt may be adjusted. The ordinary incandescent-lighting alternator of the type shown is usually wound for either 1,100 volts or 2,200 volts, as these pressures are high enough for economical distribution unless the distances are longer than are usually met with in the common run of towns or medium-sized cities.

96. Fig. 52 shows a General Electric alternator of the revolving-field belt-driven type. This machine is of 300 kilowatts capacity and is wound to deliver three-phase currents at a frequency of 60 cycles. The revolving field is seen at *A*, but a better idea as to the construction of the machine will be obtained by referring to Fig. 53. The revolving field consists of a steel ring *B* supported by the spider *c c*. The ring *B* carries the laminated pole pieces *D*, which are dovetailed into the ring as shown at *e*. In the larger machines the pole pieces are bolted to the ring. Each pole piece is provided with a field coil *d*, which, in the larger

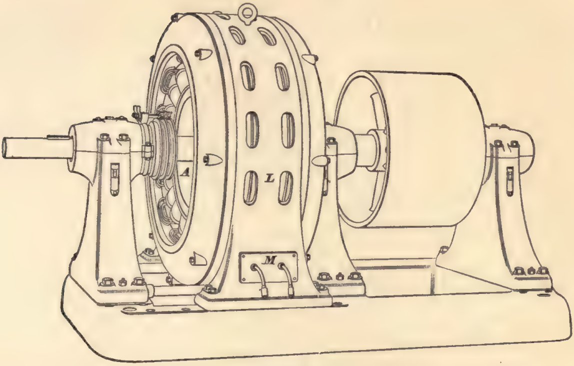


FIG. 52.

machines, is wound with copper strip placed on edge. These coils are connected in series and their terminals brought to

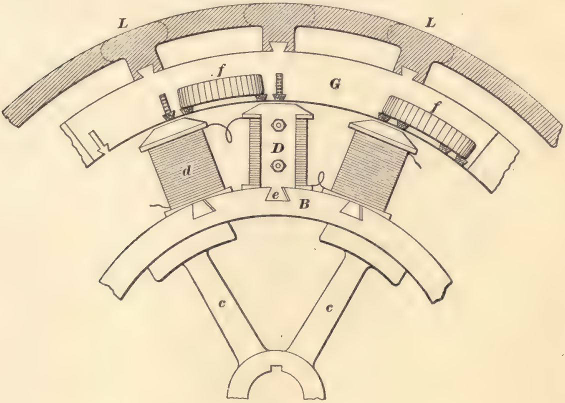


FIG. 53.

collector rings mounted on the shaft. By means of these rings the exciting current is led into the field. The stationary armature windings *f*, *f* (in this case shown for a single-phase

machine with two slots to each pole) are held in grooves around the inner periphery of the laminated core G, as shown,

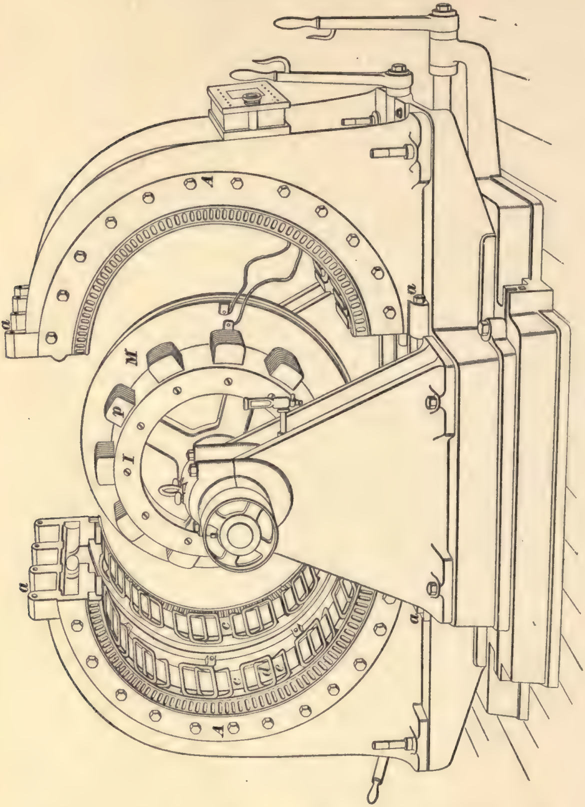


FIG. 54.

and this core is supported by the casting L, also shown in Fig. 52, attached to the base of the machine. The terminals of the stationary winding are shown at M, Fig. 52. The

whole armature structure is arranged so that it may be slid along on the base so as to give access to the field and armature coils.

97. Inductor Alternator.—Some makers have gone a step further and construct alternators without any moving wire whatever. These machines are of the **inductor** type, so called because both the armature and field-exciting coils are stationary and the magnetism passing through the armature coils is made to vary by revolving a mass of iron called an inductor. One of the most widely used of these types is the Stanley machine. These are made for several different outputs and Fig. 54 represents one of the larger sizes. In this view the two halves *A*, *A* of the stationary armature are shown drawn back so as to allow access to the coils. When the machine is in operation, these halves are bolted together by means of bolts passing through the lugs *a*, *a*. The machine is double, there being two laminated cores *c*, *c*, in the slots of which the coils *d*, *e* are mounted (see also Fig. 55). It will be noticed that the coils marked *d* are placed midway between those marked *e*, one set of coils overlapping the latter. The result of this arrangement is that when half the conductors of one set of coils is directly under the poles, the conductors of the other set are out from under the poles; hence, when the current in one set is at its maximum value, the current in the other set is at its minimum value, thus making this particular machine deliver two currents that differ in phase by 90°. The machines can also be built to supply single-phase or three-phase currents, if desired. The revolving inductor is shown at *I*, Fig. 54, surrounded by the magnetizing coil *M*. All the polar projections *p* on one side of the coil are of the same polarity, and there is a similar set of opposite polarity on the other side of the coil. The construction will be understood by referring to Fig. 55, which shows an end view and section of a large Stanley machine, the different parts being lettered to correspond with those shown in Fig. 54. The holes *f*, *f* in the armature-core stampings receive heavy iron bars that serve to hold

the core together and also to carry the magnetism. The path of the magnetic flux is indicated by the dotted line *1–2–3–4*, and when the inductor revolves, the lines of force sweep across the stationary coils and thus set up the required E. M. F. This machine has the advantage of having no moving wire about it, but machines of the revolving-field type, such as shown in Fig. 52, have the advantage of using

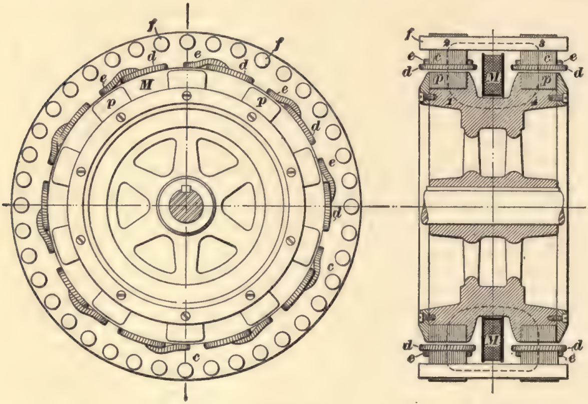


FIG. 55.

small field coils that are easily repaired or replaced in case anything goes wrong with them. A number of other types of inductor alternator are in use. The Westinghouse machine of this type is similar to the one just described and operates on the same principle, the chief difference being that there is only one armature instead of two, i. e., the double construction shown in Fig. 55 is not used. The same is true with regard to the Warren alternator.

98. Direct-Connected Alternators.—Alternators direct connected to waterwheels or steam engines are now quite common in connection with electric-lighting work. Their construction is essentially the same as that of belted

machines. Direct-connected alternators run at a lower speed than the belt-driven machines, hence, for a given frequency, they must have a larger number of poles. In order to make room for these, the machine must be large in diameter and, consequently, correspondingly narrow in the direction parallel to the shaft. Fig. 56 shows an alternator

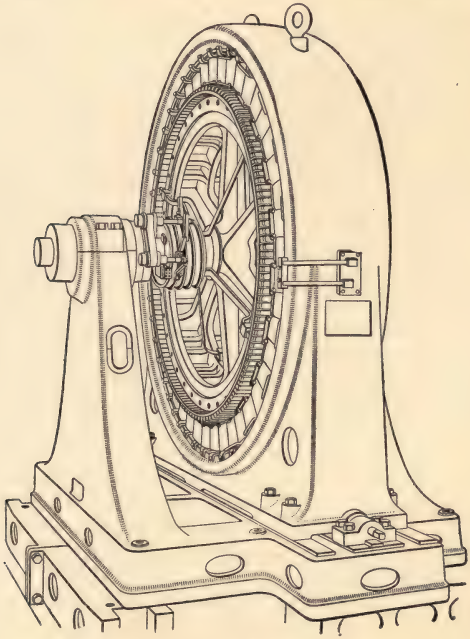


FIG. 56.

designed for direct connection to a waterwheel running 150 revolutions per minute. This machine is of 650 kilowatts capacity and is a good example of the revolving-armature and stationary-field type.

99. General Remarks.—From the foregoing it will be seen that for a given installation there is a wide variety of generating apparatus from which to choose. The question as to whether alternating or direct current shall be used is, in most cases, decided by the distance over which the current is to be transmitted; and the question as to whether direct-connected or belted machines shall be used depends on the question of first cost and the space available. Direct-connected machines cost somewhat more than belted ones of the same output, but, as the first cost and wear and tear on belts is done away with, and as the wear on the slow-speed machine is small, it may prove that the more expensive direct-connected machine is the cheaper in the long run. Again, in places where space is valuable it may be almost absolutely necessary to use direct-connected units. This is very frequently the case in city-lighting plants and in isolated plants in large buildings. In making the choice of a dynamo, then, for any particular plant, it is important that the surrounding conditions be taken into careful consideration, so that the machine that will do its work most efficiently and with the least expense for maintenance will be selected. The tendency is strongly towards the use of direct-connected machines.

ELECTRIC LIGHTING.

(PART 2.)

STATION APPLIANCES.

1. In addition to the dynamo, the equipment of an incandescent-lighting station comprises a number of appliances that are necessary for the operation of the station. These instruments are intended for the control or protection of the various machines and circuits, and they are usually grouped together and connected up on the **switchboard.** The arrangement and construction of the switchboard itself will be taken up later; for the present, we will consider briefly some of the more important appliances themselves.

The kind of instruments used in connection with the operation of the plant will depend, to a great extent, on whether direct or alternating current is used, and on whether this current is supplied at high pressure or low pressure. The appliances suitable for a 110-volt direct-current installation would not be suitable for a 2,000-volt alternating-current system. Among the more important station appliances to be considered are the following: *switches*, *bus-bars*, *voltmeters* and *ammeters*, *fuses*, *circuit-breakers*, *rheostats*, *ground detectors*, and *lightning arresters.*

SWITCHES AND BUS-BARS.

2. Low-Tension Switches.—Switches are used to disconnect a circuit or dynamo whenever desired. If the current to be handled is large, the switch must be of massive

construction. For ordinary work, where the pressure does not exceed 200 or 300 volts, plain knife switches are used. Fig. 1 shows a typical two-pole knife switch. Most of these switches are mounted directly on the slate or marble of which the switchboard is constructed, and connections are made to them by means of studs running through to the back. When the switch is opened, connection is broken between the clips *1* and *2*, *3* and *4*, thus opening both sides

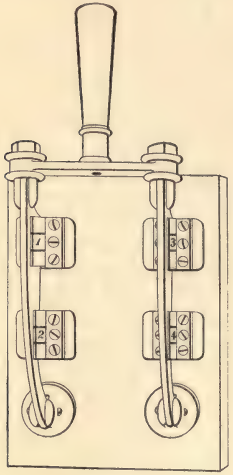


FIG. 1.

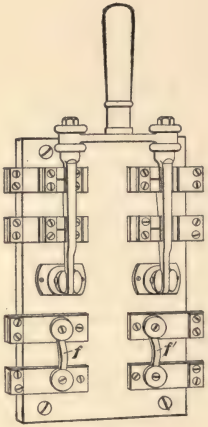


FIG. 2.

of the circuit. Knife switches should be substantially constructed and should have a contact surface at the clips of at least 1 square inch for every 80 to 100 amperes. The blades should be made of good conducting material, preferably of drawn copper, and the clips should be stiff enough to give a good, firm contact. A brass rich in copper is frequently used for such switches, but if this is done, the switches should be made to give a larger contact surface

than if pure copper blades were used. For pure copper, the blades should have a cross-sectional area of about 1 square inch for every 1,000 amperes carried. Fig. 2 shows a front-connected switch provided with fuses *f*, *f'*, and Fig. 3 shows a triple-pole switch as mounted on a switchboard and arranged for back connection. This last style is often used where compound dynamos are operated in multiple, the middle blade making the connection to the equalizing bar. Triple-pole switches are also used in connection with three-phase installations. Knife switches should always be mounted with the handle up, so that the blades are swung down in order to open the switch. This is done in accordance with a rule of the Fire Underwriters, which requires switches to be so placed that when opened they will not tend to fall closed of their own accord, but will, on the contrary, tend to remain open. All switch bases should be of incombustible material, such as marble, slate, or porcelain.

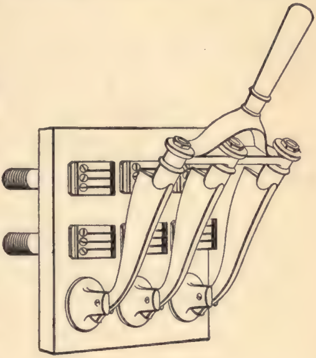


FIG. 3.

3. High-Tension Switches.—These switches are used in connection with alternating-current work where the pressure is high and where ordinary switches would not be capable of breaking the arc. A great many types of high-tension switches have been introduced, and their design depends to a large extent on the voltage to be handled. Figs. 4 and 5 show a style of quick-break switch that has proved very successful both in lighting and street-railway work. It is simple in construction, breaks the arc very quickly, and operates well on circuits where the pressure

does not exceed about 3,000 volts. The figures show the single-pole type, but it is made also for two or three poles, as may be desired. Fig. 4 shows the switch closed and Fig. 5 shows it partly opened. The switch blade, which is

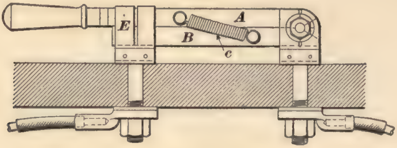


FIG. 4.

of drawn copper, is made in halves *A*, *B*, which are connected by two springs *c*, one on each side of the blade. When the handle is pulled out, the half *A* leaves the clip *E*

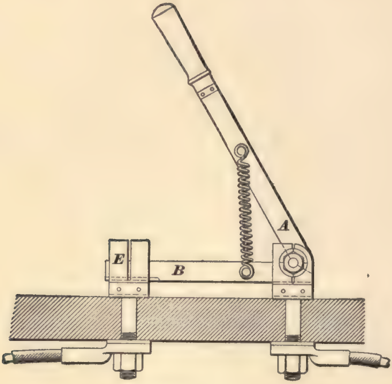


FIG. 5.

and thus stretches the springs. When the bottom blade flies out, it leaves clip *E* very quickly, owing to the action of the springs, thus drawing out the arc and breaking it almost instantaneously. The main switch on the board

shown in Fig. 60 is very similar in principle. When the blade is pulled out, a follower maintains contact until the blade has been pulled back a considerable distance, when it flies back and thus breaks the arc. When knife switches are used on high-tension boards, it is a common practice to separate the blades by marble barriers, as shown in Fig. 60, in order to prevent the arc jumping from one blade to the other.

4. Fig. 6 shows the same style switch as Fig. 4, but it is mounted so as to be capable of handling higher pressures. The switch is constructed so as to give a long, quick break, and is mounted on insulators *1*, *2*, *3*, *4*. These are made of hard rubber or similar material and are grooved so as to make the leakage path from the switch parts to the panel as long as possible. This insulating material passes through the panel, so that in no place does the metal switch stud come in contact with the marble. This is a necessary precaution in cases where very high pressures are handled, because the marble cannot be depended on to give good enough insulation. The blades *A*, *B* are arranged as described in connection with Fig. 4, except that blade *A* has a hole in the end instead of a handle. The switch is pulled open by means of a hook in the end of a handle about 3 feet long, thus allowing the attendant to stand back some distance and avoid the danger of his being burned by the arc. To avoid arcing from one switch to the next, marble barriers *C* are mounted at right angles to the main part of the board. Each switch is thus placed in a cell by itself, and arcing across from one switch to its neighbor cannot take place.

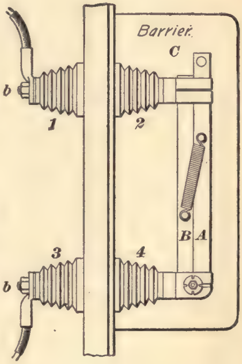


FIG. 6.

5. The Westinghouse Company make use of a high-tension switch in which the terminals are mounted at each end of a porcelain cylinder. A copper rod or plunger passes through these contacts or bushings and completes the circuit. When the plunger is withdrawn, the arc is formed in the confined space between the bushings. A small outlet is provided in the side of the tube, and when the arc is formed, the blast caused by the sudden expansion of the

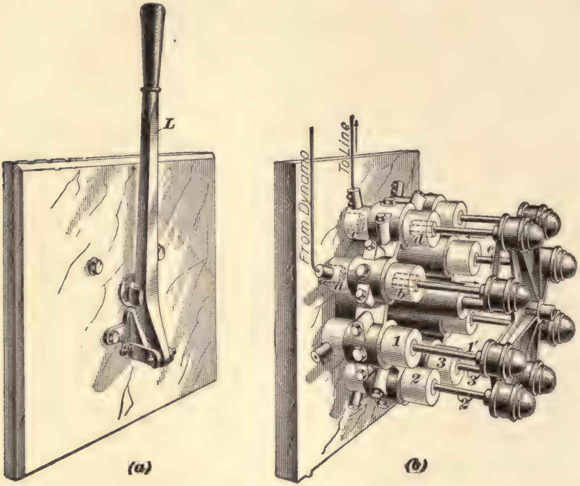


FIG. 7.

air in the confined space, together with the cooling action of the porcelain walls, extinguishes the arc. If the pressure to be handled is very high, a number of these cylinders are connected in series, thus producing a long break. Fig. 7 (*a*) and (*b*) shows a switch of the plunger type that is intended for a two-phase dynamo or circuit. This switch gives a double-pole double break in each phase. The cylinders *1*, *2*, *3*, etc. and plungers *1′*, *2′*, *3′* are mounted on the back of the board and are operated by a lever *L* on the front. The

switch must accommodate 4 dynamo wires and 4 line wires, hence there are 8 cylinders, thus giving a double break in each line. The path of the current will be understood by referring to the arrows. In the figure the switch is shown thrown out, but when the plunger is in, bushings *a* and *b*, *c* and *d* are connected together, and the path of the current is *a–b–c–d–e* to line. When the plunger is withdrawn the arc is broken between *a* and *b*, *c* and *d*.

6. When large currents at high pressures are to be handled, the General Electric Company uses switches in which the arc is broken under oil. It has been found that a comparatively short break is sufficient under such circumstances, because as soon as the arc is formed the oil rushes into the gap and extinguishes it. Switches operating on this principle are in use in a number of the larger installations. Most of the larger sizes are operated by air pressure or a small electric motor, though in some cases they are arranged for hand control.

7. The variety of switches made is very large, and in selecting them for any special line of work the main points to look out for are, first, to see that the switch is capable of carrying the current without overheating or arcing when the circuit is broken; and, second, to see that it is substantially constructed. Switches on lighting boards are open and closed quite frequently, owing to changing over the circuits and dynamos. If these switches are not strongly built, they will be continually working loose and giving trouble, hence the importance of paying close attention to the mechanical construction.

8. Bus-Bars. — On high-tension, alternating-current switchboards, the bus-bars do not need to be very heavy, but on low-tension boards, where several hundred or, perhaps, thousand amperes are handled, they must have a large cross-section. They should have a cross-section of at least 1 square inch per thousand amperes carried and should be arranged so that the heat generated in them may be readily radiated. They should always be substantially mounted

on the back of the switchboard and should be very carefully insulated. This last precaution is specially necessary in plants where the pressure between the bus-bars is high. The bars are usually of flat rectangular cross-section, and if an unusually large carrying capacity is needed, a number of these bars are built up together with air spaces between

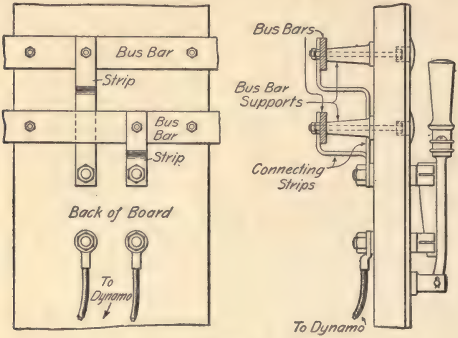


FIG. 8.

them to allow ventilation. Round bars are sometimes used, but they are not as common as the flat bars. For alternating-current bus-bars of large capacity, copper tubes are sometimes used, because, when an alternating current is sent through a heavy conductor, it is found that the current flows for the most part in the outside portion of the conductor. The method of building up bars out of thin strips, with air spaces between, is used also for alternating-current boards where a large volume of current is to be handled. The bus-bars are usually connected to the dynamo and feeder switches, either by means of copper strips, as shown in Fig. 8, or by means of cables provided with terminals, as shown in Fig. 9. All these connecting pieces should have a cross-section of not less than 1 square inch per 1,000 amperes.

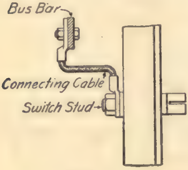


FIG. 9.

AMMETERS AND VOLTMETERS.

9. It is necessary to use ammeters in order that the current supplied by any dynamo or feeder may be seen at a glance. Voltmeters must be used in order that the pressure on the dynamo or feeders may be determined. It is usually the custom to equip each dynamo with an ammeter, or, in the case of multiphase machines, with one or more ammeters. In many cases, each feeder is also provided with an ammeter, so that the current supplied to any particular part of the system may be determined. Feeder ammeters are, however, not always considered essential, and, as a rule, one or two voltmeters are sufficient for most installations. It is unnecessary to go to the expense of installing a voltmeter for each machine or feeder, because a switch or series of plug connections can easily be provided, by means of which the voltmeter may be connected to any dynamo or circuit in order to obtain a reading. Ammeters and voltmeters are generally very similar in construction, the main difference being that the ammeter is of low resistance and is connected in series in the circuit; whereas, the voltmeter is of high resistance and is connected across the circuit. Some kinds of meters will operate with either direct or alternating current; others will work on direct current only. Most of the instruments in use are electromagnetic in principle.

10. Weston Ammeters and Voltmeters.—The Weston instruments are probably more widely used on switchboards than any others intended for direct current. Weston ammeters and voltmeters of the direct-current type should never be connected upon alternating-current circuits. A swinging coil *c*, Fig. 10, is mounted so as to swing between the pole pieces *N*, *S* of a permanent magnet. Current is led into the coil by means of the spiral springs *s*, *s'*, which also serve to counterbalance the movement of the coil. When a current flows through the coil, it reacts on the magnetic field, and causes it to swing around like the armature of an electric motor. It is evident that if an alternating current were

sent through the instrument, the coil would tend to swing first in one direction and then in the other, so that no deflection would result. The switchboard, Fig. 56, shows the type

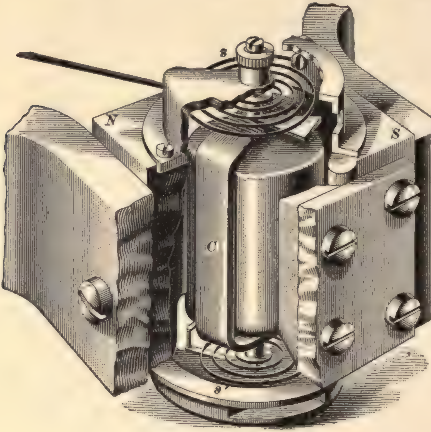


FIG 10.

of Weston instruments used for switchboard work. The voltmeter V and ammeter M are mounted in iron cases, and the dial is ruled on opal glass, which is illuminated from behind by means of incandescent lamps. The cheaper style, or "round type," without illuminated dials, is shown by the ammeters *a*, *a*. The voltmeters have a high-resistance coil mounted in the case and connected in series with

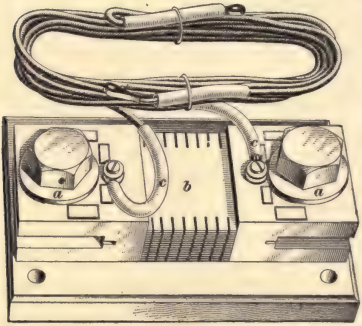


FIG. 11.

the swinging coil. In the case of the ammeter, it is not possible to send all the current through the coil, so only a small proportion of it is used; the remainder passes through the **ammeter shunt.** The ammeter shunt shown in Fig. 11 is a very low resistance, which is connected in series in the circuit the current in which is to be measured. For example, suppose the dynamo *A*, Fig. 12, supplies current to the bus-bars *B*, *C*, and we wish to connect an ammeter so as to measure the current supplied by the dynamo. The ammeter shunt *S* would be connected in series, as shown, and two small wires *1*, *2* taken from the terminals of the shunt to the ammeter *M*.

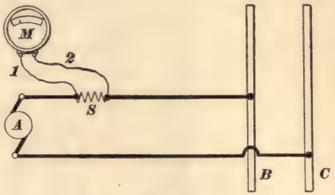


FIG. 12.

The result of this arrangement is that only a small portion of the current passes through the instrument. But as the resistance of the shunt and ammeter is fixed with regard to each other, it follows that the current through the ammeter will always be a fixed proportion of that in the main circuit, and the scale may be marked so as to read the main current and not the current actually flowing through the meter. The use of a shunt is of great convenience, because it does away with the necessity of running heavy connections to the meter itself. The shunt may be placed at any convenient point, and it is an easy matter to run the light flexible connections from it. It may be well to state here that the small connecting cables running from the shunt to the instrument are sent out with the shunt. They are usually made long enough to reach any reasonable distance on the switchboard. They should on no account be altered in length; if they are too long, they should be coiled up out of the way; if too short, another shunt with long leads with its corresponding instrument should be obtained.

Fig. 11 shows the ordinary type of shunt used. It consists of the two terminals *a*, *a* connected together by the flat

strips *b*, which are made of an alloy that has practically a constant resistance regardless of temperature changes; *c*, *c* are the small flexible cables that run to the ammeter.

The shunts and instruments are always numbered to correspond, and care should be taken to see that these numbers match before connecting up the instruments. Many other makes of instrument other than the Weston are used in connection with shunts.

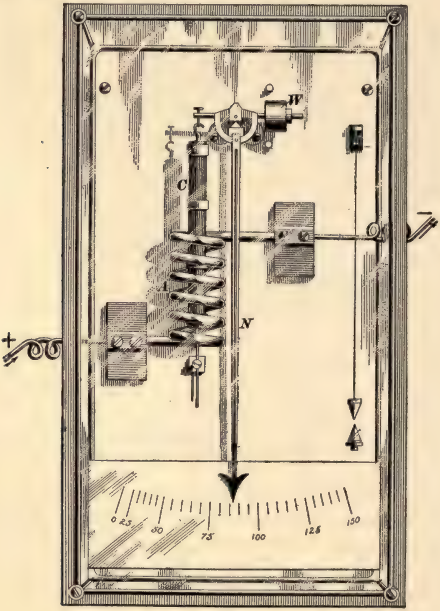


FIG. 13.

11. Alternating-Current Ammeters and Voltmeters. Most of the switchboard ammeters and voltmeters for alternating current consist of a coil arranged so that the magnetic field set up through it will act on a piece of iron,

the movements of which actuate a pointer. Various modifications of this coil-and-plunger type are in common use. For example, in the earlier type of Westinghouse instruments, Fig. 13, a vertical coil A is arranged so as to draw an iron core C into it. This core is hung on one end of a balance arm to which the pointer N is attached, and a counterweight W is hung from the other end. In the later instruments, the current is sent through a coil, and the magnetic field produced deflects a small iron vane placed within it. Fig. 14 illustrates the principle of a type of instrument that has been largely used by the General Electric Company, both for alternating and direct current. It is known as the Thomson inclined-coil pattern. The coil c,

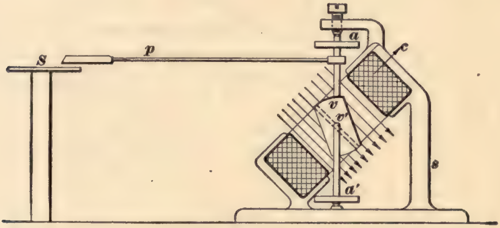


FIG. 14.

through which the current flows, is mounted on an angle, as shown. A vertical shaft passes through the coil, and on it is mounted a small iron vane v. This vane is mounted at an angle to the shaft, and when the hand is at the zero position, the vane lies at an angle to the lines of force that, when a current flows, thread through the coil as shown by the arrows. As soon as a field is set up through the coil, the vane swings around so that it tends to lie parallel to the lines of force, as indicated by the dotted lines v', thus giving a reading on the scale S. The movement of the needle p is controlled by means of the springs a, a'. The instruments shown on the alternating-current switchboard, Fig. 60, are of this type.

12. Potential Transformers.—It is not usual to connect voltmeters of the ordinary type directly across the line

FIG. 15.

on alternating-current boards, because the pressure is so great that a voltmeter would have to have an exceedingly high resistance to permit its being so connected. Of course, if the pressure were low they could be connected in the ordinary way. In case the pressure is high, a small **potential transformer** is used to step down the voltage. Fig. 15 shows a transformer of this kind. It is generally mounted on the back of the switchboard; its primary coil is connected to the line and its secondary to the voltmeter, as shown in Fig. 16. It is bad practice to run switchboard lamps from the potential transformer, because, as a rule, the transformer does not have sufficient capacity for this purpose, and, besides, it is liable to interfere seriously with the accuracy of the voltmeter readings. The voltmeters are usually graduated to read the secondary voltage, as this is what is generally required. In some cases, however, they are graduated so as to read the primary voltage.

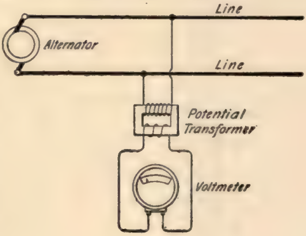


FIG. 16.

13. Current Transformers.—Alternating-current ammeters are in most cases connected directly in circuit. Shunts cannot, as a rule, be used with alternating-current ammeters, because, on account of the self-induction of the coil in the instrument, the current will not divide proportionally. Generally, the current

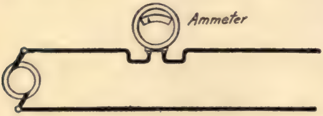


FIG. 17.

to be handled on an alternating-current board is comparatively small, because the pressures used are high and there is no great difficulty in running the main wire directly through the instrument, as shown in Fig. 17. If, however, the current is large, or, what is often the case, if the generator pressure is so high that it is not desirable to have the main wires in contact with the instrument in any way, a **current transformer** is inserted in the circuit, as shown in Fig. 18. This is a small transformer, of which the primary coil *P* consists of a few turns of heavy conductor sufficiently large to carry the whole current. In some cases, where the current is very large, there may be only a fraction of a turn. The secondary *S* is of small wire and consists of a comparatively large number of turns. The secondary is connected to the ammeter, and as the current increases in the primary, it causes a proportional increase in the current through the ammeter. The ammeter may thus be calibrated so as to indicate the main current, though the main current does not actually pass through it, and it is at the same time entirely disconnected from the high-pressure dynamo leads.

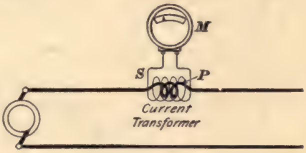


FIG. 18.

14. Electrostatic Voltmeters.—There is one kind of voltmeter that is sometimes used, especially for high-pressure alternating-current work, that differs considerably from the instruments so far described, both as to its construction and principle of operation. This is the **electrostatic voltmeter.** It depends for its action on the principle that two bodies carrying similar static charges repel each other and those carrying unlike charges attract each other. Fig. 19 shows the construction of the Stanley electrostatic voltmeter. *B*, *B* and *C*, *C* are fixed plates mounted on a hard-rubber base. These plates are covered with a hard-rubber covering *H* to prevent the charge from leaking off, also to

obviate any danger of short-circuiting between the vanes. *A* is a movable aluminum vane, to which is attached the pointer, the movement of which is counterbalanced by the

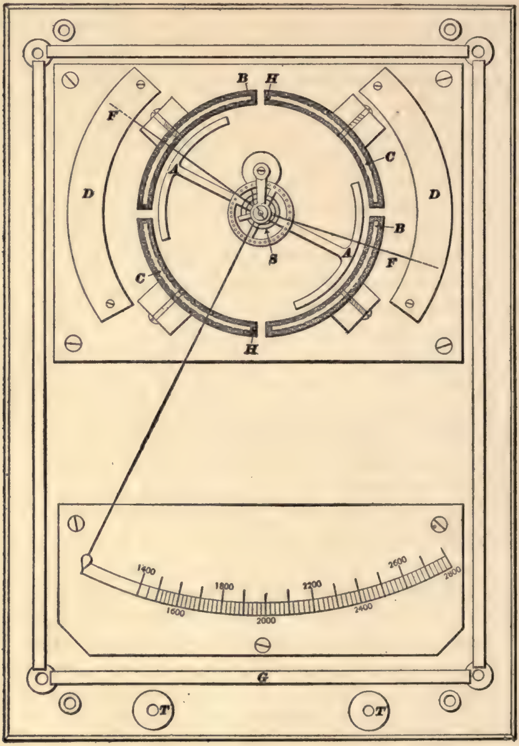


FIG. 19.

spiral spring *S*. The fixed plates *B*, *B* and the movable vane *A* are connected together and form one pole of the instrument. The fixed plates *C*, *C* are connected together and form the other pole. When the voltmeter is connected

to the circuit, *B* and *A* being charged alike will repel each other, while at the same time *C* and *A* will attract each other, with the result that the vane is deflected an amount depending on the pressure of the circuit. Two plug receptacles *T*, *T* are provided on the instrument, in addition to the regular terminals, so that it may be compared at any time with a standard instrument. The movement of the needle is damped or steadied by the vanes *F* moving in the partially closed boxes *D*.

Other types of electrostatic instruments are made, but they all work on about the same principle. They do not, of course, require any current for their operation and can be connected across high-pressure lines without the intervention of a potential transformer.

15. Voltmeter Switches and Connections.—It has already been stated that it is customary to make one voltmeter answer for several dynamos or circuits by using a

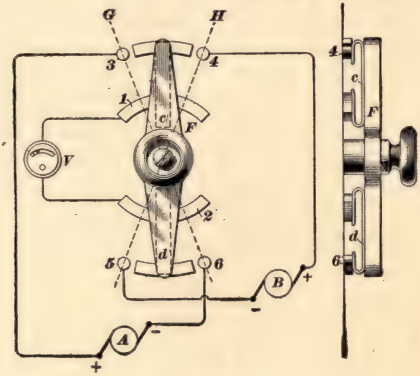


FIG. 20.

voltmeter switch or plug. Fig. 20 shows one of the simplest forms of switch used for this purpose. This is suitable for two dynamos, and its method of operation is obvious from the figure. The voltmeter is connected to terminals *1* and *2*,

and the dynamos *A*, *B* to *3* and *6*, *4* and *5*. Connection is made to the terminals *3*, *4*, *5*, *6* by means of the spring contact pieces *c*, *d* that are attached to the insulating cross-arm *F* and rub on the arcs *1* and *2*. In position *G*, machine *A* is connected to the voltmeter, and in position *H*,

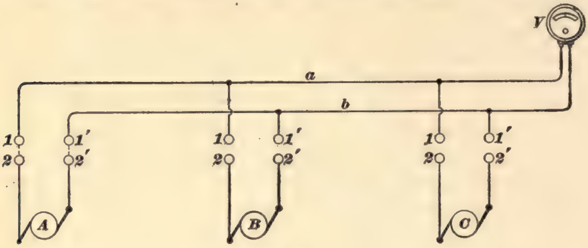


FIG. 21.

machine *B* is connected. Sometimes voltmeters are connected by means of a flexible cable that is attached to a plug that may be inserted in receptacles connected to the different dynamos. The use of a cable is, however, somewhat objectionable, and in order that it may be avoided, the plugging arrangement shown in Fig. 21 has been largely adopted. A pair of wires *a*, *b* are connected to the voltmeter *V*, and taps are run from these to the plug receptacles *1*, *1′*. The different dynamos are connected to receptacles *2*, *2′*, and when a voltmeter reading from any generator is desired, a plug is inserted into the receptacle corresponding to that generator. This plug is arranged somewhat as shown in Fig. 22, and when it is inserted, it connects points *1* and *2*, *1′* and *2′* together, as indicated by the dotted lines, Fig. 21.

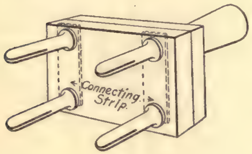


FIG. 22

16. Pressure Wires.—In most cases, it is necessary to know the pressure that is being maintained at the center of distribution, where the light is supplied, rather than at the

station; i. e., the voltmeter should give indications of the pressure delivered, and the pressure at the generator will be greater than this by the amount of the drop in the line. In order to indicate the pressure delivered, it has been customary in some cases to run *pressure wires* back to the station from the distributing center, as shown in Fig. 23. The wires *a*, *b* run back from the distributing center *c* and

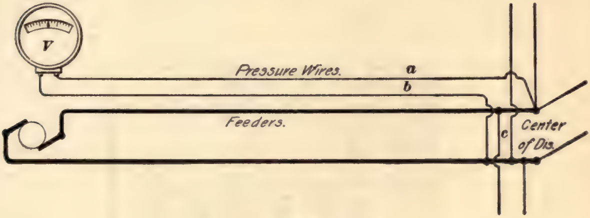


FIG. 23.

connect to the voltmeter *V*, either directly or through a potential transformer, as the case may be. The current required to operate the voltmeter is so small that there is practically no drop in the pressure wires. The pressure wires are of small cross-section, usually No. 8 or 10 when strung on poles. Insulated iron wire is often used for this purpose, as the current to be carried is very small.

17. Compensating Voltmeter.—In order to avoid the necessity of running pressure wires back to the station, **compensating voltmeters** or **compensators** are sometimes used in connection with alternating plants. The compensator is a device used in connection with the voltmeter to decrease the voltmeter reading by an amount proportional to the drop in the line as the load increases. The attendant then increases the field excitation of the alternator and thus brings the pressure up to such an amount that the voltage at the distributing point is correct. Fig. 24 shows the general appearance of the Westinghouse compensator, and Fig. 25 shows how it is used in connection with the voltmeter. It consists of a small

transformer, the primary of which is divided into a number of sections with leads brought out to terminal blocks *R*, *S*, *T*, etc., Fig. 24. The secondary is also divided into a number of sections with terminals brought to the contact points *1*, *2*, *3*, etc. The voltmeter is of the ordinary coil-and-plunger type with a small auxiliary coil *c*, Fig. 25, wound over the main coil *d*. The main coil is supplied with current from the potential transformer *T* in the ordinary way. The primary of the compensator is connected in series with the

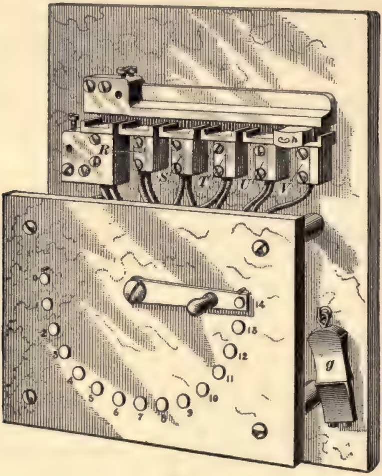


FIG. 24.

main circuit, as shown, and the secondary is connected to the small auxiliary coil. When the voltage at the distributing end of the line is at its correct value, the hand of the voltmeter is at its mid-position. When the load increases, the current through the primary of the compensator also increases; this, in turn, increases the current in the secondary, which is so connected to the auxiliary coil that the current in this coil opposes that in the main coil. The

result is that the hand on the voltmeter goes back, and the pressure must be raised to bring it up to its proper value. By plugging in at different points on the primary and by setting at different points on the secondary, the compensator may be adjusted for operation on almost any of the circuits ordinarily met. After it is once set to suit the particular

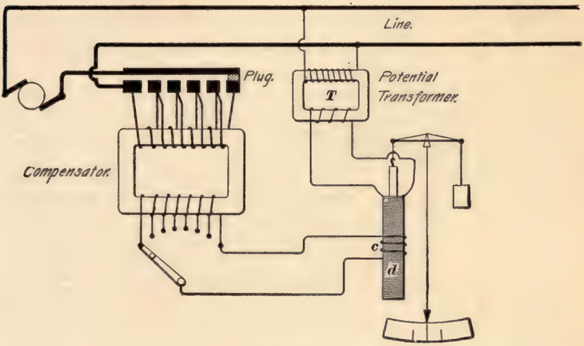


FIG. 25.

line on which it is to work, it requires no further attention. Tables are furnished with the instrument showing how to set it, and care must be taken in setting to insert the extra plug *g*, Fig. 24, before withdrawing the plug *h* already in use, otherwise the circuit will be opened.

18. The Mershon Compensator.—The compensator described in the last article answers very well for lines that have little self-induction and that supply a lamp load. Where, however, the load is inductive, as, for example, a load of motors or a load of motors and lamps, the reactance of the line may have a very great influence on the drop in voltage, and if a compensator is to make the voltmeter give indications that are at all accurate, it must compensate not only for the ohmic drop in the line, but also for the drop due to the reactance. The Mershon compensator, brought

out by the Westinghouse Company, is designed to accomplish this.

19. The principle on which this compensator operates is

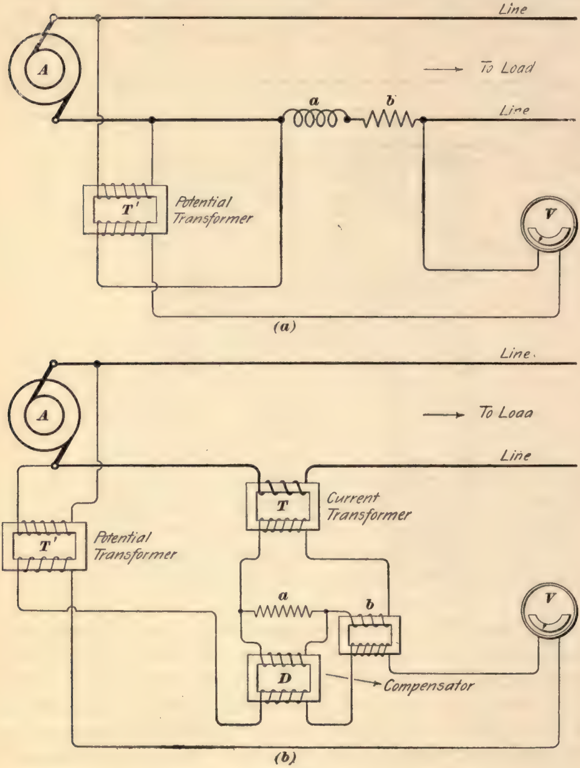


FIG. 26.

briefly as follows: The E. M. F. supplied at the end of the line is always equal to the resultant difference between the

E. M. F. generated and the E. M. F.'s necessary to overcome the resistance and reactance. If, then, three E. M. F.'s are set up at the station that are proportional to the above three E. M. F.'s and bear the same phase relation with regard to one another, and if these E. M. F.'s are combined in the same way as the line E. M. F.'s, it is evident that their resultant will make the voltmeter indicate the E. M. F. at the end of the line. For example, take the simple case shown in Fig. 26 (*a*). *A* is an alternator supplying current to the line. *T'* is an ordinary potential transformer, the secondary of which gives a voltage that is proportional to the generator voltage and in step with it. If the voltmeter *V* were connected directly to *T'*, it would evidently indicate the station voltage, but what is wanted is an indication of the voltage at the far end of the line, and in order to get this, the voltage of *T'* must be reduced by an amount equal to the sum of the drops caused by the reactance and resistance. In order to do this, an adjustable reactance *a* and an adjustable resistance *b* are inserted in the circuit. The drop through *b* will be proportional to and in step with the line-resistance drop; the voltage across *a* will be proportional to and in phase with the inductive drop. From the way in which the connections are made, it is easily seen that the voltage acting on *V* is a combination of the voltages of *T'*, *a*, and *b*. The drop across *a* and *b* will increase as the current in the line increases, hence the voltmeter reading will decrease (because the connections are made, so that the pressures across *a* and *b* cut down the E. M. F. applied to *V*). The voltmeter will, therefore, indicate the true pressure at the end of the line because both the ohmic and inductive drops are accounted for.

Fig. 26 (*a*) is intended to illustrate the principle only, the actual connections are more nearly as indicated in Fig. 26 (*b*). Here *A* is the alternator, as before, and *T'* the ordinary potential transformer. *T* is a small current transformer, the primary of which is connected in series with the line and the secondary to the compensator proper, which consists of three parts, *a*, *b*, and *D*. The E. M. F.

generated in the secondary of T' is proportional to and in step with the generator E. M. F. The current in the secondary of T is proportional to the load; a is a non-inductive resistance and b is a reactance coil wound on an iron core. These coils are connected in series, and the current supplied from the secondary of T passes through them. The E. M. F. across a is, therefore, in step with and proportional to the resistance drop in the line; while that across b is in step with and proportional to the back E. M. F. due to the reactance of the line. D is a small transformer in shunt with a; its secondary E. M. F. is in step with and proportional to the E. M. F. across a; b is also provided with a secondary that gives an E. M. F. in step with and proportional to the E. M. F. across b. All these devices, i. e., a, b, and D, are in one piece of apparatus, and terminals from the secondaries of D and b are brought out to two multipoint switches, so that the number of turns in each may be adjusted to suit different lines. The voltmeter V indicates the resultant voltage, as already explained. For three-phase circuits, a and b are supplied from two series transformers whose primaries are connected in series with two of the lines and whose secondaries are in parallel, so that the current supplied to a and b is a combination of the two. Complete instructions for adjusting the compensator are furnished by the makers.

FUSES AND CIRCUIT-BREAKERS.

20. Fuses and circuit-breakers are used on the switchboard to prevent injury to the machines from short circuits or overloads. It must be remembered that the dynamos used for incandescent lighting or power-distribution work maintain a constant pressure. Hence, if the outside resistance be reduced to a very low value, as it would be in case of a short circuit, a large rush of current would be the result. Short circuits may thus cause considerable damage unless the circuit is promptly opened.

21. Fuses.—A fuse consists of a piece of wire or strip made of a fusible alloy; usually a mixture of lead and bismuth, though very often fuses are made of copper or aluminum. This fuse is inserted in the circuit at some convenient point on the switchboard, and is made of such size that it will melt and break the circuit whenever the current exceeds the allowable amount. The switch, Fig. 2, is provided with ordinary link fuses, shown at f, f'.

For low-tension work, plain open fuses are commonly used; but for high-tension work, it is necessary to have them arranged so that the arc formed when they blow will not hold over and destroy the terminals and fuse holder. Moreover, it is necessary to have high-tension fuses arranged so that they can be renewed without danger to the switchboard attendant. In order to prevent arcing, the fuses are enclosed; and to do away with danger, they are made so that the holder may be entirely removed from the board when the fuse is to be renewed.

22. Fig. 27 (*a*) shows a type of fuse block used by the General Electric Company on alternating-current switchboards; (*b*) shows the shape of the aluminum fuse used in the block. The fuse holder is made in two parts, the lower part A being of porcelain and the upper part B of lignum vitæ. The lower part is provided with blades c that fit between the clips d, d', Fig. 27 (*a*), in the same way as the blades of a knife switch. These clips lie in slots in the marble board F and are connected to the line and dynamo by means of terminals g and h. By adopting this arrangement, the whole block may be detached from the board by simply pulling it straight out, thus pulling the blades out of the clips. Extra blocks may be kept on hand, ready fused, and one of these put in place of the blown fuse with very little delay or danger to the attendant. The fuse is shown at l, and is clamped by means of the screws m, n. A vent hole p is provided in the lignum-vitæ cover and the rush of air through this vent, together with the confined space, results in the suppression of the arc. When fuses are being

replaced, care should be taken to see that the switch connecting the fuse block with the dynamo is open. This fuse block is suitable for currents up to 150 amperes at 2,500 volts, and is the type of fuse shown on the switchboard in Fig. 60. For higher pressures fuse blocks are used in which the fuse is pulled wide apart as soon as it blows, thus breaking the arc.

The use of fuses on low-tension lighting switchboards is not as common as it once was, their place being taken by the automatic circuit-breaker. Fuses are, however, used

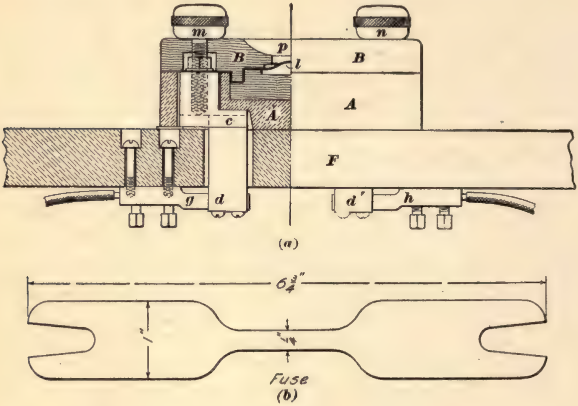


FIG. 27.

largely for alternating-current boards and also for protecting individual circuits on low-tension, direct-current boards. They are not as convenient or reliable as circuit-breakers, because it takes time to replace them when they blow, and only too often they are replaced by a heavier fuse or even a copper wire, which is of scarcely any use as a protection. Again, fuses of the same size do not always blow at the same current, as much depends on the nature of the fuse-block terminals. If the clamps are not screwed up tightly,

local heating will result, and the fuse will blow with a smaller current than it should. Also, it has been found that a fuse of a given cross-section and material will carry a heavier current when the distance between the terminals is short than when it is long, on account of the conducting away of the heat by the terminals.

23. Circuit-Breakers.—The circuit-breaker is essentially an automatic switch that opens the circuit whenever the current becomes too large. The current is usually sent

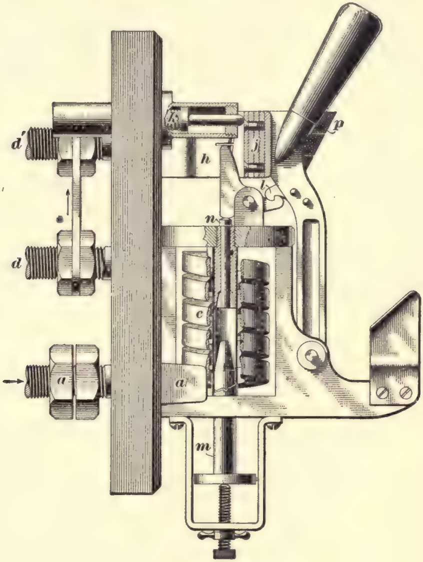


FIG. 28.

through an electromagnet or solenoid, which operates a trip and releases the switch when the current exceeds the amount for which the breaker is set. Fig. 28 shows a typical

circuit-breaker in the closed position. The current enters at *a*, passes through the coil *c* to stud *d*, thence to stud *d'* and clip *h*, across through the cross-connecting piece *j* to a similar clip not shown in the figure. The arm carrying the crosspiece *j* is held in against the action of the spring *k* by means of the catch *l*. When the current reaches the amount for which the breaker is adjusted, the plunger *m* is drawn up, hitting the rod *n* a blow and releasing the catch. This allows the arm to fly out, thus breaking the circuit by pushing the blades at each end of *j* out of clips *h*. Fig. 29 shows a front view of the same style of breaker. The arc is not broken at the copper contact clips, as they are provided with auxiliary carbon contacts *p* that remain in contact shortly after the blades are pulled out of the clips. Whatever burning action is due to the arc will take place on the carbon pieces, which are easily renewed. The current at which the breaker trips may be varied by adjusting the position of the plunger in the coil, the current for which it is set being indicated by the scale *s*, Fig. 29. The switchboard, Fig. 56, is equipped with a circuit-breaker for each dynamo and each feeder. The board shown in Fig. 58 is equipped with a circuit-breaker for each dynamo, the individual lighting circuits being equipped with fuses only. The circuit-breakers shown on both these boards are of the Westinghouse type and are very similar in design to the one already described.

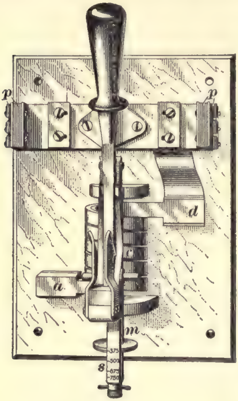


FIG. 29.

24. Fig. 30 (*a*) and (*b*) shows another type of circuit-breaker, which is designed for use on 125- to 250-volt direct-current circuits. One of the principal features of this breaker is the style of main contact used. It consists of a

U-shaped brush *a* made of a large number of thin copper leaves, and when the breaker is closed this brush is pressed firmly against the contacts by means of a togglejoint.

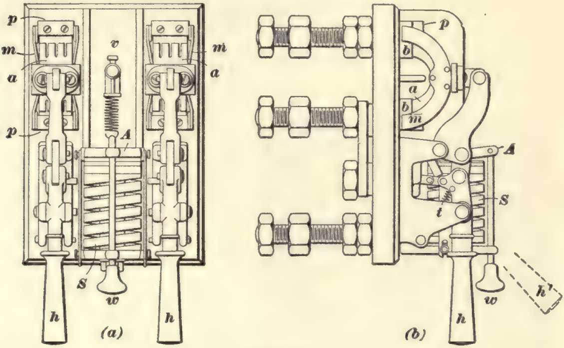


FIG. 30.

Fig. 31 shows how the laminated contact completes the circuit, and the method of mounting the lever will be seen by referring to Fig. 30, in which *a*, *a* are the main laminated contacts and *b*, *b* the terminals against which they are pressed when the handle *h* is forced in. Each main contact

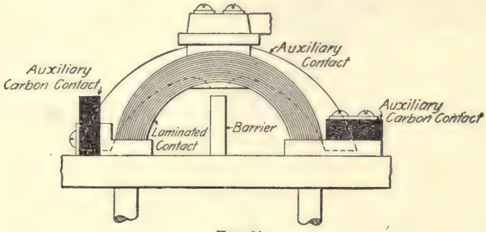


FIG. 31.

is provided with a pair of light auxiliary contacts *m*, *m* that can be easily renewed. These wipers press against the carbon blocks *p*, *p*, and when the breaker flies out the arc is broken between the carbon blocks and the wipers, because these do not break connection until after the main contact.

By using the togglejoint to force the main contact into place and to close the breaker, a comparatively light pressure on the handle is sufficient to force the contacts firmly together, a feature that makes the breaker easy to set. Another advantage of this style of contact is that it is not likely to stick. The tripping coil is shown at *S*, and when the current becomes excessive, the armature *A* is attracted and trips the breaker, which is promptly opened by the spring *t*. The current for which the breaker is set may be adjusted by means of the screw *v* and the breaker may be tripped by hand at any time by pulling down on the knob *w*. The breaker shown is a double-pole, but each side of the circuit is independent of the other. For example, if there should happen to be a short circuit on the line, one side may be closed and then the other. If the short circuit were still present, the first side would fly out as soon as the second was closed, thus protecting the dynamos and apparatus. The above type of circuit-breaker is also made single-pole, as in Fig. 32.

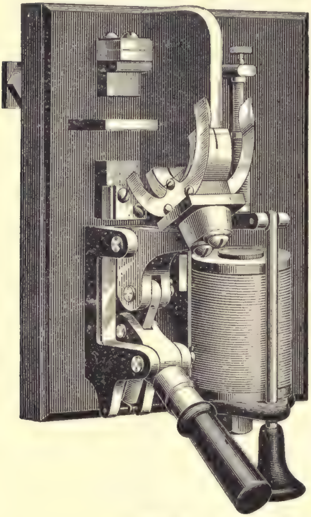


FIG. 32.

RHEOSTATS.

25. Every direct-current dynamo should be equipped with a rheostat in its shunt field, so that the generator voltage may be adjusted. Alternators are usually provided

with a rheostat in series with their separately excited field, as well as with one in the shunt field of the exciter. In some cases, the latter alone is used, although it is desirable to have a rheostat in the alternator field, and it is almost absolutely necessary if the plant is arranged so that one exciter may supply the fields of several machines, as is frequently done in large plants. The method of connecting rheostats will be shown later, when the subject of switchboard connections is taken up.

26. The rheostat usually consists of a number of coils made up of iron, German-silver, or other wire having a high resistance. These coils may be mounted in a variety of ways. Sometimes they are wound in spiral form and mounted in a cast-iron box. In other cases, they are mounted on an iron plate and bedded in enamel. Whatever method is used, the mounting should be perfectly fireproof and at the same time allow the coils to radiate the heat readily. The resistance is divided into a large number of sections, so that the current in the shunt field may be varied by small amounts, thus giving a correspondingly fine adjustment of E. M. F. It may be mentioned, in passing, that the field rheostat used in connection with a compound-wound machine is not usually varied to any great extent after the machine has settled down to its normal operation. When the dynamo is first started up, its fields are cold, but after it has been running a while, they warm up and their resistance increases so that it is necessary to cut out some of the rheostat in order to keep up the voltage. However, after the fields have reached their normal temperature, the compound coils will generally take care of the voltage, and very little further adjustment of the field rheostat is necessary. Field rheostats are made in many different styles, and a great many different schemes have been adopted for making up and mounting the resistance.

Fig. 33 shows the appearance of a typical field rheostat mounted in an iron box and arranged for attachment to the front of the switchboard. The resistance is here divided

into 52 sections connected to the contact points p mounted on the slate front. By turning the hand wheel H, any number of sections may be cut in or out. Nearly all rheostats are made so that turning the handle to the right will cut in resistance and lower the voltage of the dynamo. This is the same direction that an ordinary globe valve is turned to shut off the steam or water. On most modern slate or marble boards, the rheostat is mounted on the back of the panel, and all that appears on the front is the hand-wheel necessary for operating it.

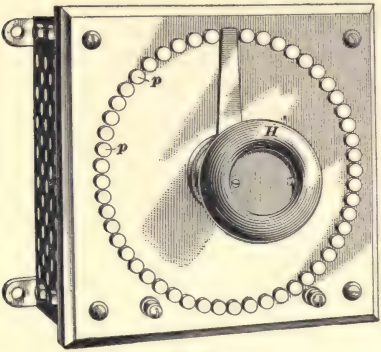


FIG. 33.

Fig. 34 shows a rheostat arranged in this way. The one shown is of the enamel type, in which the wire is made up into flat zigzag coils and embedded in enamel on the back of a ribbed iron plate. This holds the wire securely in place and at the same time allows it to impart the heat generated to the ribbed iron plate, which radiates it. The figure shows the operating wheel H that moves the arm a over the contacts b; t, t' are the terminals of the rheostat, and the whole is bolted to the panel by means of bolts c.

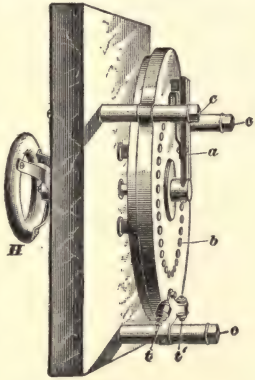


FIG. 34.

GROUND DETECTORS.

27. It is necessary to have some device by means of which grounds on the system may be detected. A voltmeter makes a very good ground detector, because it not

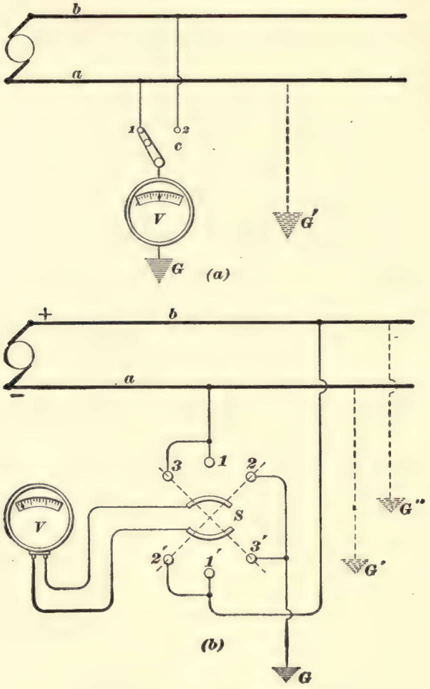


FIG. 35.

only indicates whether a ground is present, but by its deflection it shows whether the path of the current to ground is one of high resistance or low resistance.

In order to indicate grounds, the voltmeter may be connected as shown in Fig. 35 (*a*); *a* and *b* are the mains connected to a two-point switch; *c*, the blade, is connected through the voltmeter *V* to the ground. If the line *a* should become grounded, as indicated by the dotted line, and the switch blade placed on point *1*, no deflection would result. If, however, the blade is moved to point *2*, current will pass from line *a* through the ground on the line to the voltmeter to point *2*, and thence to the line *b*, thus completing the circuit. When a deflection is obtained on point *2*, it shows that line *a* is grounded; and when obtained on point *1*, it shows that line *b* is grounded. If the ground is of high resistance, the deflection will be comparatively small; if of low resistance, the deflection will be large. Many direct-current voltmeters, for example, the Weston, require that the current shall flow in them always in the same direction, in order that they may give a deflection over the scale. In Fig. 35 (*a*), it is easily seen that the current will flow through the voltmeter in the opposite direction on point *2* from what it will on point *1*, hence the voltmeter must have its zero point in the center of the scale, so that it can read either way.

Most voltmeters have their zero point at the left-hand end of the scale, and it is often convenient to have a switch that will allow the ordinary voltmeter to be used either as a voltmeter or ground detector. Fig. 35 (*b*) shows an arrangement for doing this. The switch *S* is similar in construction to that shown in Fig. 20, but the connections are arranged so that when the switch is in the position *1–1'*, the voltmeter *V* is connected directly across the line and gives the voltage on the system. When the switch is in the position *3–3'*, the voltmeter indicates any grounds, such as G'', that may be present on line *b*. When *S* occupies the position *2–2'*, *V* indicates grounds on line *a*, as at G'. By tracing out the path of the current in each case, the student will see that the current always flows through the voltmeter in the same direction.

28. Another very common arrangement for detecting grounds is shown in Fig. 36. Here two lamps *c*, *d* are connected in series across the lines. The voltage at which these lamps are designed to run is equal to that of the dynamo, so that when the two are connected in series, they will burn dull red. At the point between the lamps, a connection is made to ground through a switch or a push button *f*. If contact is made at *f* and if there is no ground on either line, the brilliancy of either lamp will not be altered. Suppose, however, that there is a ground on *b*, as indicated at G'. Now when the key is pressed, hardly any current will flow through lamp *d*, because the current will flow through *c* and *f* to the ground and thence to line *b*. In other words, lamp *d* will be shunted by the ground and it will go out. On the other hand, the cutting out of the high resistance of lamp *d* in series with *c* results in *c* burning brighter. The lamp that is connected to the side of the circuit on which the ground exists goes out or becomes dimmer, while the lamp on the other side brightens up correspondingly. This lamp detector is simple, and while it serves as an indicator of grounds, it is hardly as satisfactory as the voltmeter detector, as it does not give as accurate indications as to the resistance of the fault.

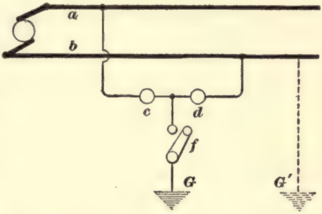


FIG. 36.

29. Fig. 37 shows a ground detector that is suitable for a three-wire low-tension system. Three lamps l_1, l_2, l_3 are connected in series across one side of the system, and a ground connection is made at *x* through key *K*. When all three lines are clear of grounds, the lamps will burn at a dull red, they will all be equal in brightness, and their color will not change when key *K* is pressed. Suppose that line *C* becomes grounded at G'; then, when *K* is pressed, lamp l_1

will be connected across lines B, C, and lamps l_1 and l_2 will be cut out; l_1 and l_2 will therefore go out, and l_3 will come up to full candlepower. If a ground occurs at G'' on line B, lamp l_3 will go out and l_1, l_2 will brighten up, but will not come up to full candlepower because two of them will be in series between B and C. If there is a ground at G''' on line A, all the lamps will come up to full candlepower, because they will all get the full voltage, l_3 being across A B and l_1, l_2 in series across A C. It is thus seen that a ground on any one of the three lines affects the lamps differently, so that by noting their performance, the line on which there is a ground may be located.

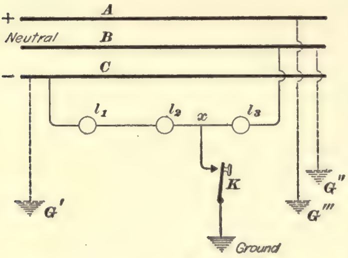


FIG. 37.

30. The ground detectors just described apply more particularly to low-tension direct-current installations, but similar arrangements may be used on alternating-current systems by using potential transformers. Fig. 38 shows the method used by the Westinghouse Company on some of their alternating-current switchboards. The regular voltmeter V, with which the switchboard is equipped, is here used also as a ground detector. P is a plug switch by means of which

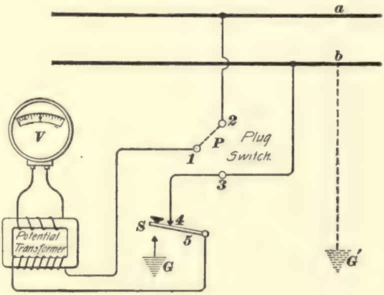


FIG. 38.

points *1* and *2* or *1* and *3* may be connected together. Under ordinary conditions, the plug is in *1* and *2*, thus connecting the primary of the potential transformer across the line, and *V* serves as an ordinary voltmeter. *S* is a key, or push button, that, when pressed, connects one side of the line to ground through the transformer primary. If there happens to be a ground on the side *b*, as shown at *G'*, the voltmeter will give a reading, and the attendant can judge by the size of the deflection as to whether the ground is a serious one or not. The path of the current is *b*–*G'*–*G*–*5*–to primary–*1*–*2*–*a*. By placing the plug in points *1* and *3*, side *a* may be tested. When the key *S* is not pressed, the lever *5* is against contact *4*, so that *V* is connected as an ordinary voltmeter.

31. A ground detector that is suitable for high-tension alternating-current systems is shown in Fig. 39. This is

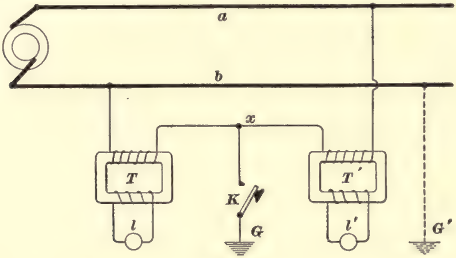


FIG. 39.

one of the earlier types used by the Westinghouse Company, and is similar in principle to the lamp detector shown in Fig. 36. The only difference is that the lamps are operated by means of transformers *T*, *T'*. These transformers have their primaries connected in series across the high-tension lines and the middle point *x* can be connected to ground through the key *K*. The secondaries are connected directly to the lamps *l*, *l'*. If line *b* is grounded and *K* pressed, the primary of *T* will be cut out and lamp *l* will go out. Lamp *l'* will brighten up. When there are no grounds on the line,

both lamps will burn dim and at equal brightness whether *K* is pressed or not.

32. Fig. 40 shows a form of alternating-current ground detector of which there are a considerable number in use. It was formerly used by the Thomson-Houston and General Electric Companies, but it has been replaced by the electrostatic ground detector in later installations. The principle of the electrostatic ground detector will be described later.

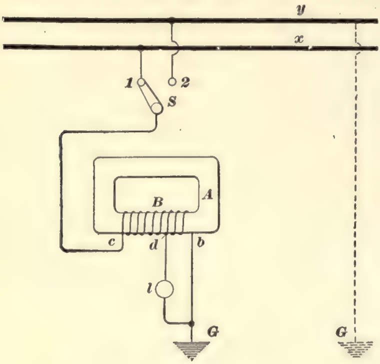


FIG. 40.

In Fig. 40, *A* represents a laminated iron core similar to a regular transformer core. On it is wound the coil *B*. One end of the coil *c* is arranged so that it may be connected to either side of the circuit through switch *S*, and the other end *b* is connected to the ground. A tap is brought from a point *d* and is connected to the lamp *l*, and the other terminal of *l* is connected to the ground. Suppose there is no ground on either line wire. Then if the switch is put on either points *1* or *2* the lamp will remain dark, because no current will flow through coil *B* to the ground. If there is a ground on the line *y* and the switch is placed on *1*, then current will flow from *y* to the ground, through *B*, and back to *x* by way of the switch and point *1*. This current will magnetize the core and set up a counter E. M. F. in coil *B*. The E. M. F. set up in the portion of the coil *d b* will cause the lamp to glow and thus indicate the ground. If the lamp glows when the switch is placed on point *2*, it indicates that there is a ground on line *x*.

In some forms of this ground dectector the switch is replaced by an insulated handle with a terminal on the end. This terminal is connected, by means of a flexible cable, to one terminal of coil B, and when tests are being made, the terminal is simply brought into contact with the various lines. This simplifies matters considerably where there are several circuits to be tested and avoids having a two-point switch for each pair of lines. Fig. 41 shows this type of ground detector provided with a plug p, by means of which it may be connected to any of the lines.

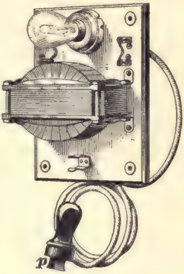


FIG. 41.

33. Electrostatic Ground Detector.—Ground detectors operating on the electrostatic principle are used to quite a large extent. They have the advantage that they require no current for their operation and may be left connected to the circuit all the time, thus indicating a ground as soon as it occurs. They also give an indication without it being necessary to make an actual connection between the line and ground, as is the case with all the detectors previously described. Fig. 42 illustrates the principle of the later style of Stanley electrostatic ground detector, which is specially adapted to high-pressure alternating-current lines because the instrument is not in actual connection with either of the lines. The instrument itself is enclosed in a hard-rubber casing and the parts are very similar to those of the voltmeter shown in Fig. 19. The fixed vanes *1* and *4*, *2* and *3* are connected together in pairs, as shown. The movable vane V is connected to the ground and is held in the central position shown in the figure by means of small spiral springs S. The pairs of fixed plates are not connected direct to the lines, but are attached to plates a, a' of two small condensers. These condensers consist simply of two brass plates a, b that are mounted in hard rubber at some distance from each other. Plates b, b' are connected

to the lines. When no grounds are present, *1* and *4*, *2* and *3* become oppositely charged by reason of charges induced on plates *a*, *a′* by *b*, *b′*. At any instant the charge on vanes *1* and *4* will be similar to that on *B;* at the same time the charge on vanes *2* and *3* will be similar to that on *A*. The forces acting on the vane *V* are, therefore, equal and opposite. Now suppose that line *B* becomes grounded at *G″*. This is equivalent to connecting vane *V* to line *B;* *V* takes up a charge similar to *1* and 4, hence it is repelled by *1* and *4*, and is attracted by *2* and *3*, thus giving a deflection. If *A* becomes

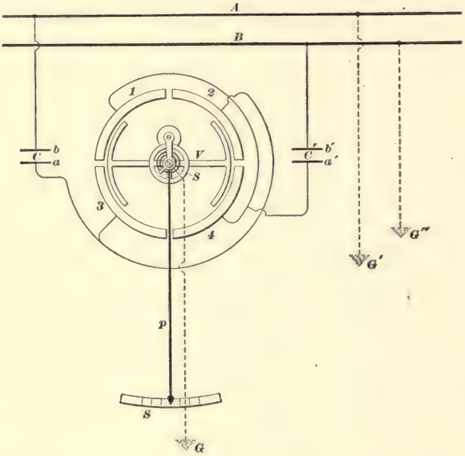


FIG. 42.

grounded, a deflection in the opposite direction is obtained. Instruments of this kind can, of course, only be used in places where the pressure is fairly high, as the electrostatic forces produced by charges due to low pressures would not be large enough to operate an instrument unless it were made much too delicate to be of practical use in a light or power station. In most electrostatic detectors, the lines are connected directly to the fixed sectors *1*, *2*, *3*, *4* and the condensers *C*, *C′* are omitted.

LIGHTNING ARRESTERS.

ARRESTERS FOR DIRECT CURRENT.

34. The general principles relating to lightning arresters have already been discussed, and we will here confine our attention to a description of some of the more common types that are used in connection with electric-lighting work. The arrester used for any given lighting system must be selected with due reference to the voltage and kind of current used. Arresters that would work well on alternating-current lines might be total failures when used with direct current, owing to their inability to put out the arc following the discharge. On the other hand, some arresters will work equally well either on direct or alternating current.

35. The Garton Arrester.—Fig. 43 illustrates the Garton arrester. The discharge points are of carbon, shown at *h* and *j*. These points are about $\frac{1}{32}$ inch apart, and the lower one is connected to ground; *f* is a coil of wire wound on the tube *g*, which is closed at the top; *e* is a small core of iron attached to the rod *d*, which in turn connects, by means of a small flexible cable, to one end of the resistance *b*. The other end of the coil connects to the other end of the resistance, to which the line also connects. The resistance *b* is made up of a stick of graphite and, having practically no inductance, it offers little or no opposition to the discharge. The discharge comes in over the line *a*, passes through *b* to the rod *d*, thence to the carbon point *h*, and jumps the air gap to the ground. The discharge is followed by current from the dynamo and, since the coil is in shunt with the resistance,

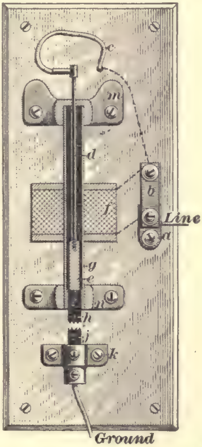


FIG. 43.

part of this current will flow through the coil, thus drawing up the core *e* and breaking the arc between *e* and *h*. The fact that the arc also takes place in the enclosed tube tends to put it out. As soon as the discharge has passed, the core drops back and the arrester is ready for the next discharge. This arrester is very simple and is not liable to get out of order. The spark gap should be examined now and then to see that it has not become enlarged or

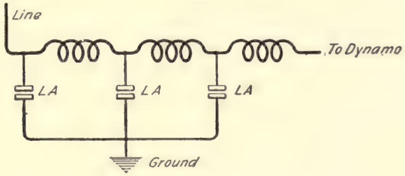


FIG. 44.

blocked up in any way. If the gap becomes too long, the lower carbon may be moved up a little. Sometimes arresters are connected as shown in Fig. 44, as this arrangement gives especially good protection. Here three kicking coils are connected in series and a lightning arrester is connected in ahead of each coil. The Garton arrester may be used on either direct-current or alternating-current circuits.

36. Westinghouse Arrester.—Fig. 45 shows the form of the Westinghouse arrester that is used on direct-current circuits. This arrester has no movable parts, and the arc is extinguished by smothering it in a confined space. Two terminals *b*, *b* are mounted on a lignum-vitæ block and are separated by a space somewhat less than ½ inch. This space is crossed by a number of charred grooves, so that although the resistance in ohms between the terminals is very high, yet the lightning will readily leap across the space. The block *A* is covered by a second

block, not shown in the figure, that excludes the air and confines the arc to the small space between the terminals. When the arc tends to follow the discharge, the small space is soon filled with the vapor of the metallic electrodes that will not support combustion, and the arc is put out. The connections of the arrester are very simple, one side being connected to the line and the other to ground. It should be noted that this arrester is intended for use on direct-current circuits only, and the pressure should not exceed 600 or 700 volts.

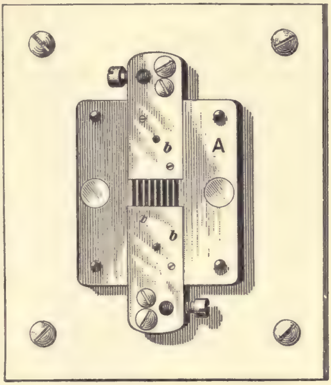


FIG. 45.

37. Magnetic Blow-Out Arresters.—Fig. 46 shows a lightning arrester that has been used extensively by the General Electric Company for low-pressure direct-current circuits. It is of the magnetic blow-out type, i. e., the arc that follows the discharge is extinguished by forcing it across a magnetic field until it is stretched out to such a length that it can no longer be maintained. The construction of the arrester will be understood by referring to Fig. 46. A, A are two coils of wire wound on the cores B, so that when current flows through them, poles

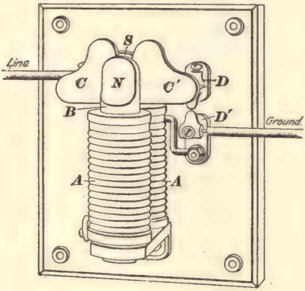


FIG. 46.

are formed at *N*, *S*, and a magnetic field is set up in the space between them. *C*, *C'* are the two electrodes, separated by a small air gap, between which the lightning jumps when it comes in over the line. *D*, *D'* are two terminals with a small gap between them. This auxiliary gap is provided in order that the discharge may pass to the ground without having to pass through coils *A*, *A*, which have considerable self-induction and which would therefore oppose the discharge. The connections of the arrester for one side of the circuit are shown in Fig. 47, and the action is as follows: When a lightning discharge comes in

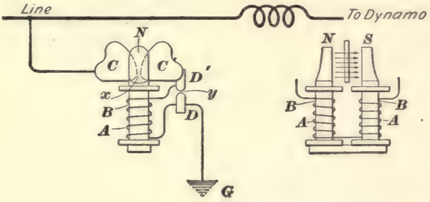


FIG. 47.

over the line, it jumps the gap between *C C'* and also that between *D D'* and passes to the ground. If a discharge happens to come over the other side of the circuit at the same time (and this would usually be the case, because the line wires run side by side), there will be a rush of current from the dynamo across gaps *x*, *y* to the ground. Of this current, a considerable part will pass through coils *A*, because these are connected in shunt across the gap *y*. The result is that a magnetic field is set up between poles *N*, *S*, and the arc formed between the electrodes is forced across the field. On account of the shape of the electrodes *C*, *C'*, the arc is stretched out as it is forced up and is finally broken. The coils *A* carry current only when the arrester is in action, and hence the arrester may be connected to any low-tension line independent of the current supplied over the line.

38. One of the objections to the arrester just described is that the discharge must jump a comparatively long air gap before reaching the ground. In a later type of magnetic blow-out arrester, the length of gap is much shorter. Fig. 48 shows the external appearance of this arrester, and Fig. 49 (*a*) and (*b*) shows the arrangement of the parts. Fig. 50 shows how the arrester is connected. All the parts are mounted on porcelain. Fig. 49 (*b*) shows the porcelain box that holds the blow-out coil *c* with its polar projections *h*, *h*, also the graphite resistance *r*. The electrodes are mounted in the cover, Fig. 49 (*a*), in connection with the clips *k'*, *k'*. When the

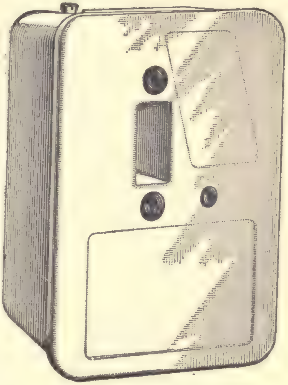
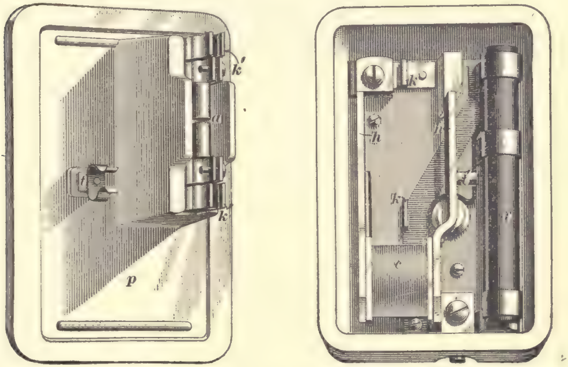


FIG. 48.



(*a*) (*b*)

FIG. 49.

cover is in place, as shown in Fig. 48, clips k', k' make contact with the tongues k, k, and we have the scheme of connections shown in Fig. 50. Here a represents the air gap, shown also at a, Fig. 49 (a), $x\ y$ is the blow-out coil, $r\ r'$ the graphite resistance. The ground connection is made to the lower end l of the resistance, and the line is connected to the upper electrode. A reactance or kicking coil may be inserted, as shown at L, as an additional precaution. The terminals of the blow-out coil connect to z and p, so that the coil is in parallel with a portion of the resistance. When a discharge comes in over the line, it jumps the air gap and passes to the ground through the resistance, following the path a–n–z–l–G. When the current follows the discharge, part of it takes the path n–x–y–p–r'–l–G, passing through the blow-out coil. By examining Fig. 49 (a) and (b), the student will notice that, when the cover is placed in position and held in place by clip t, the air gap a falls between the pole pieces h, h. The result is that as soon as an arc is formed it is blown out through the opening shown in the cover, Fig. 48, and at once extinguished. It will be noted that a portion of the resistance r' is in series with the coil and spark gap, and thus limits the amount of current that tends to follow the discharge. The ordinary type of this arrester is suitable for any direct-current circuit using pressures of 850 volts or less. It has been very largely used on street-railway lines but it is also well adapted for low-tension lighting work. The air gap is quite short (about .025 inch), and the electrodes should be examined from time to time to see that the air gap does not become larger or bridged over. If the gap becomes larger, there is danger of the lightning puncturing the insulation of

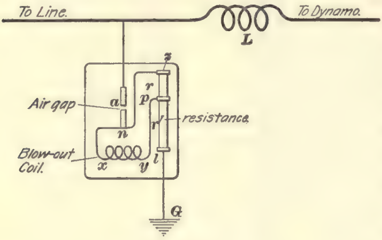


FIG. 50.

the apparatus to be protected instead of passing through the gap. The length of the air gap may be adjusted by loosening the clamps and moving the electrodes nearer together.

ARRESTERS FOR ALTERNATING CURRENT.

39. Westinghouse Arrester for Alternating Current.—Fig. 51 shows a type of arrester that has been largely used by the Westinghouse Company on alternating-current circuits. It is known as the *Wurts non-arcing arrester*, and consists of a number of milled cylinders *a*, *a* mounted as shown and separated from each other by small air

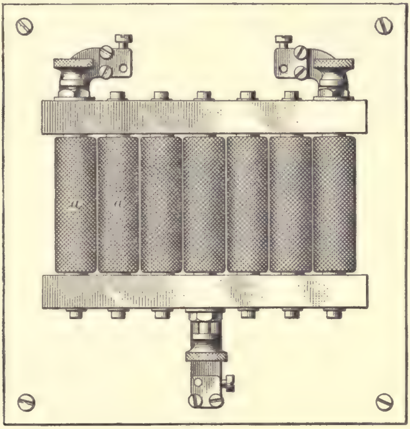


FIG. 51.

gaps. The end cylinders are connected to the lines and the middle cylinder to the ground. With this arrangement, a single arrester does for both sides of the line; where, however, the line pressure is high, a separate arrester is used for each side; and for very high pressures, such as are used on long-distance lines, a number of arresters are connected in series. When a discharge comes in over the line, it jumps

the gaps between the cylinders and passes to the ground. It is claimed that the arc does not hold over, because the gases formed by the volatilization of the metal will not support an arc. The cylinders are made of what is known as non-arcing metal. Others claim that the suppression of the arc is due to the cooling effect of the cylinders and the

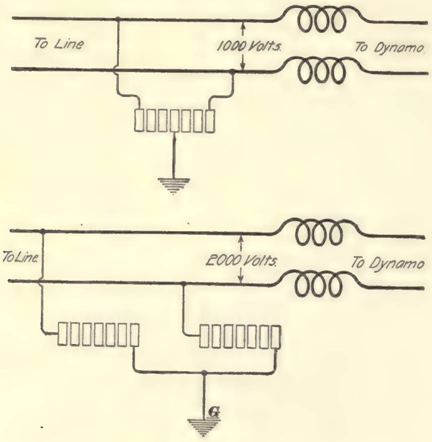


FIG. 52.

alternating nature of the current. The arc will be destructive if these arresters are used on direct-current circuits, but it will not be maintained on alternating-current circuits. The arresters should be examined from time to time and the cylinders rotated slightly so that they will present fresh surfaces to each other. Fig. 52 shows the method of connecting these arresters on 1,000-volt and 2,000-volt circuits.

40. General Electric Arrester for Alternating Current.—Fig. 53 shows an arrester used by the General Electric Company for alternating-current circuits. It is somewhat similar to the Wurts arrester just described,

except that fewer spark gaps are used and a non-inductive resistance *r* is inserted in the circuit in order to limit the current following the discharge. The spark gaps *a*, *a* are between the heavy metal cylinders *b*, *b*, *b*, the middle one of which is connected to ground in the double-pole arrester shown. The makers claim that the arcing is suppressed by the cooling effect of the heavy cylinders. This arrester, like the previous one, is not suitable for use on direct-current circuits. Fig. 54 shows this arrester connected on a 1,000-volt circuit.

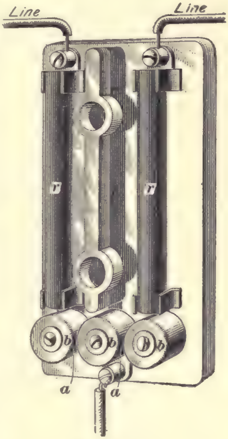


FIG. 53.

41. The arresters just described have been shown as arranged for indoor use in the station. They may, however, be used on the line, in which case they should be mounted in a weather-proof box made of iron or wood. A wooden box will answer every purpose if it is substantially made and painted with weather-proof paint. Where the pressure on the circuit is higher than that for which the

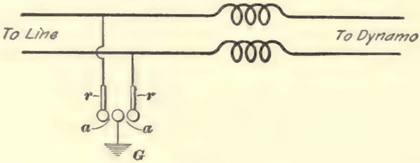


FIG. 54.

standard arresters are made, it is usual to connect a number of arresters in series (see Fig. 52). The connections to and from the arresters should be made with wire not less than No. 4 B. & S. and all connections should be run as straight as possible.

SWITCHBOARDS.

42. The **switchboard** is a necessary part of every plant. Its object is to group together at some convenient and accessible point the necessary apparatus for controlling and distributing the current to the various circuits, and the safety devices for properly protecting the lines and machines. The different pieces of apparatus used in this connection, and which are mounted on the switchboard, have already been described. Sometimes the lightning arresters are placed at the point where the wires enter the building, but in a great many cases they are mounted on the back of the switchboard. Scarcely any two switchboards are alike in every particular; their layout and the type of apparatus used on them depend on the character of the system used, the number and size of dynamos, the number of circuits supplied, etc.

43. General Construction.—Switchboards were formerly made of wood and consisted simply of a built-up board or wall sufficiently large to accommodate the instruments. This construction was objectionable on account of the fire risk, and the only type of wooden board that is now allowed by the Fire Underwriters consists of a skeleton frame of well-seasoned hardwood filled and varnished to prevent absorption of moisture. A skeleton board of this kind is cheap and is suitable for those places where the expense of a slate or marble board is not warranted. Modern boards are nearly always made of slate, marble, soapstone, or brick tile. Slate is usually satisfactory for low-tension work, but it should be avoided on high-tension boards, because it is liable to contain metallic veins. The parts of the switches, etc. are nearly always mounted directly on the board, and if any metallic veins are present there will be leakage. A good quality of marble is the material generally used for modern boards. The slabs making the boards may vary from $\frac{3}{4}$ inch to 2 inches in thickness, depending on their size. Most central-station slate or marble boards are made 2 inches thick with a bevel around the edge of $\frac{1}{2}$ inch or $\frac{3}{8}$ inch.

They are supported by bolting to angle irons, *i*, *i*, Fig. 55, and are stood out from the wall by means of braces *b*, *b*. Station boards built up as shown in Fig. 55 are usually about 90 inches high. It has become customary to build up boards in panels, each panel carrying the apparatus necessary for a generator or one or more feeders. Those carrying the instruments for the generators are known as **generator**

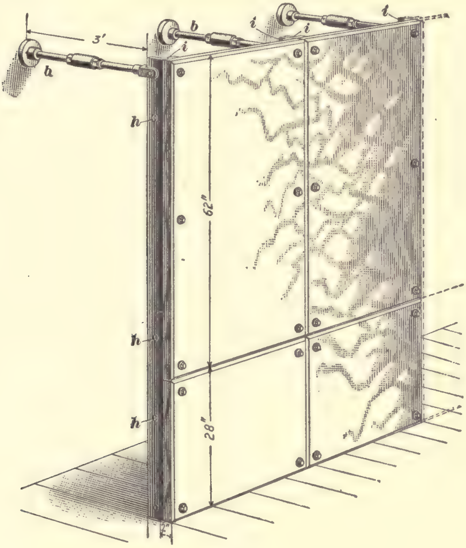


FIG. 55.

panels; those carrying the instruments for the feeders as **feeder panels.** This system allows the board to be easily extended as the plant grows in size, as additional panels can be added to those already in use. The extra panels are attached to those already installed, as indicated by the dotted lines in Fig. 55, the panels being held together by means of bolts passing through holes *h* in the angle iron.

DIRECT-CURRENT SWITCHBOARDS.

44. Fig. 56 shows a typical direct-current board arranged for two generators and three feeders. *A* and *B* are the generator panels, *D* and *E* the feeder panels, the panel *E* accommodating two feeders. In the center of the board is a panel *C* that accommodates the ammeter *M*, which is so connected as to indicate the total current output of the two

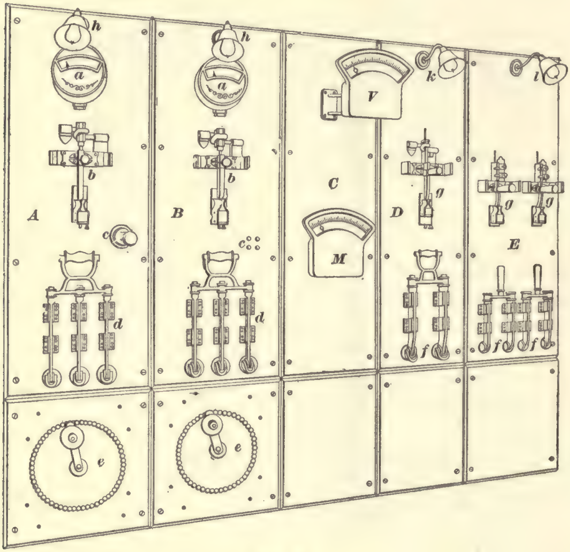


FIG. 56.

dynamos. This panel also carries the station voltmeter *V*, which is mounted on a bracket, so that it may be set at whatever angle it may be seen to best advantage. Each generator panel is equipped with an ammeter *a*, a circuit-breaker *b*, voltmeter plug and receptacle *c*, main switch *d*, and rheostat *e*. If lightning arresters are used, they are mounted on the back of the board. Triple-pole generator

switches *d* are used so that the machines may be operated in parallel. Each feeder is provided with a switch *f* and circuit-breaker *g*. On many boards, each feeder is also provided with an ammeter. Each generator panel is also provided with a pilot lamp *h*, which is connected back of the main switch, so that it will show when the generator is up to voltage, even if the main switch is not in. The exact arrangement of the wiring on the back of the board may be varied somewhat, but Fig. 57 indicates the general scheme of connections for a board of this kind. The various parts in the diagram are lettered to correspond with Fig. 56. The main dynamo leads and equalizer leads connect to the lower terminals of the main switches *d*. The upper + terminal of each switch *d* connects directly to the + bus-bar. The equalizer terminals are connected to the equalizer bar $E' E'$, so that when the main switches are thrown in, the series coils are connected in parallel. The upper − terminal of each switch connects to the − bus-bar, after first being led through the ammeter shunt *s* and the circuit-breaker *b*. It would not do to connect the ammeter shunt and circuit-breaker in the side to which the equalizer is connected, because part of the current may flow through the equalizer, and the ammeter would not indicate the full output of the machine. All the current delivered by the machine thus passes through the circuit-breaker and ammeter shunt. The ammeter *a* is connected to its shunt *s* by means of the small cables furnished with the instrument. The lower terminals of the voltmeter receptacles *c*, *c* are connected to the + and − sides of the machines, as shown. It should be noted that these connections are made to the lower terminals of the main switch, so that voltmeter readings may be obtained before the switches are thrown in. The pilot lamps *h*, *h* are also connected to the same lines, so that they will indicate when the machine is up to voltage. The upper terminals of the voltmeter receptacle are connected to the voltmeter *V*, so that by inserting the plug, the voltmeter may be connected to either dynamo. The + and − bus-bars run across the back of the board to the feeder panels.

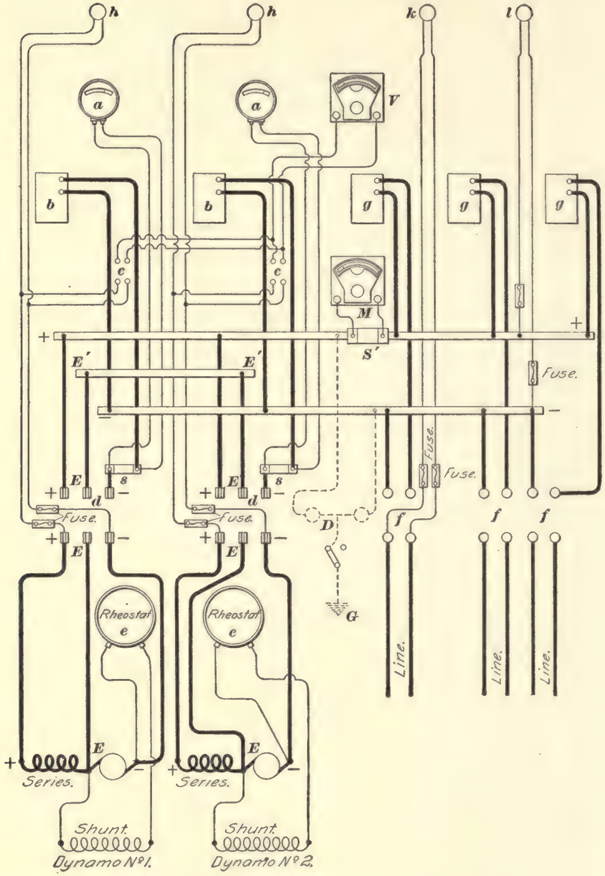

h
h
k
l
a
a
V
b
b
g
g
g
c
c
M
+
S′
E′
E′
Fuse.
–
Fuse.
Fuse.
E
s
E
s
d
d
Fuse.
Fuse.
D
f
f
f
E
E
G
Rheostat
e
Rheostat
e
Line.
Line.
Line.
E
E
Series.
Series.
Shunt.
Shunt.
Dynamo No. 1.
Dynamo No. 2.

FIG. 57.

Between the generator and feeder panels, the shunt S' for the main ammeter M is inserted, so that the total current supplied by the two machines must pass through the shunt, and the ammeter M thus indicates the total current output. The method of connecting the bus-bars to the feeders depends to some extent on whether the feeders are to pass out at the top of the board or whether they are to be carried down through the floor. In this case, they are shown connected to the bottom terminals of the switches and carried downwards. One side of each feeder switch is connected directly to the − bus-bar; the other side connects to the + bus-bar through the circuit-breaker *g*. Lamps *k* and *l* may be connected directly across the bus-bars, or, if desired, they may be made to indicate when a circuit-breaker is out by connecting to the outgoing terminals of the feeder switch. Lamp *k* is shown connected in this way; lamp *l* is shown connected directly across the bus-bars. Small fuses are inserted in the various lamp circuits to prevent any danger from short circuits. This board is not shown equipped with a ground detector, but if such were required, it could be connected as shown at *D*. Each line should also be provided with a lightning arrester if they connect to overhead lines. These arresters would be arranged in connection with kicking coils, as previously described. The student should trace out carefully the connections given on the above board; by doing so, he will soon become familiar with the method of arranging and connecting the various parts.

45. The direct-current switchboard shown in Fig. 56 is of fairly large capacity and is suitable for a plant where a comparatively few number of feeders of large capacity are supplied. For isolated plants in stores, moderate-sized office buildings, and factories, the output of the machines is not so large and such a heavily constructed board is not necessary. Fig. 58 shows a typical board for an isolated plant. This is arranged for five feeders and two dynamos. The panels *A* and *C* accommodate the generator apparatus and the center panel *B* carries the five double-pole feeder

switches *s*. Each of these switches is provided with fuses *f*, as the current handled on each circuit is comparatively small and circuit-breakers are hardly necessary. Each generator is provided with a triple-pole main switch *S* and a circuit-breaker *M*; *N*, *N* are the ammeters, one for each generator, and *V* is the voltmeter, which may be connected

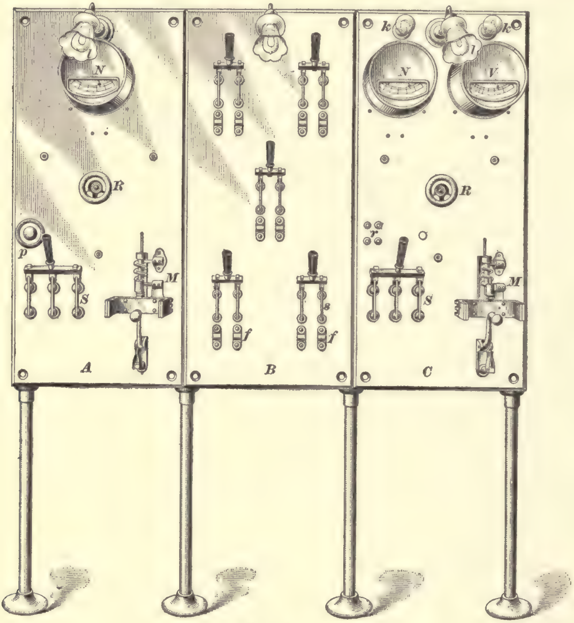


FIG. 58.

to either generator by means of the plug *p* and receptacles *r*. The lamps *l*, *l* are connected back of the main switch, so as to act as pilot lamps. The lamps *k*, *k* are for detecting grounds as previously explained. If a cheaper installation were required, main fuses might be substituted for the circuit-breakers *M*, but otherwise the board shows about

the minimum amount of apparatus required for operating two dynamos singly or in parallel on five feeders. Fig. 59 shows the general scheme of connections with the exception of those for the ground detector, which have been omitted, as they are not essential. From the explanation already given with Fig. 57, there should be little difficulty in tracing them out. This is left as an exercise for the student.

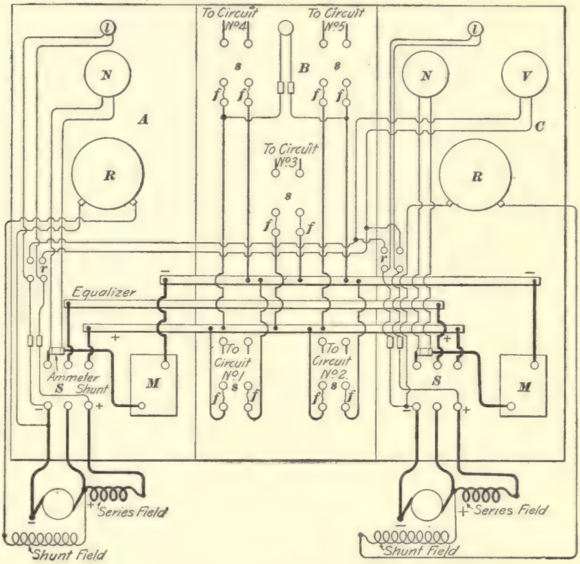


FIG. 59.

46. On both the above boards, the equalizing connection is shown as running to the switchboard and connected to the middle blade of the triple-pole switch. This is the general practice where the dynamos are of comparatively small capacity; but for large units it is now considered better practice, on the whole, to use double-pole or two single-pole switches on the board instead of one triple-pole,

and run the equalizing connection directly between the machines. In this case, each dynamo is provided with a separate single-pole equalizing switch mounted on a stand near the machine.

ALTERNATING-CURRENT SWITCHBOARDS.

47. The arrangement of ordinary alternating-current boards is, in many respects, similar to that of direct-current boards. They are usually built up in panels in the same way as the boards previously described. Owing to the fact that alternators are generally separately excited, the switchboard contains some extra apparatus connected with the exciter that is not found on direct-current boards. The wiring and connections will also depend on whether single-phase or polyphase alternators are used, and whether these machines are to be arranged for parallel running or not. It is thus seen that the number of different styles of board that may be used is very large. The following is intended merely to bring out some of the more important points concerning the arrangement of such boards.

48. Single-Phase Generator Panel.—Fig. 60 (*a*) and (*b*) gives front and rear views of a typical alternating-current panel for one single-phase generator. Such a board would be used where only one single-phase machine is operated on a single line, and represents about as simple an arrangement as possible. This panel is equipped with the following apparatus: main switch *a*, electrostatic ground detector *b*, voltmeter *c*, ammeter *d*, field switch *f*, generator rheostat *g*, exciter rheostat *h*, main fuses *k*, and potential transformer *t*. The main switch *a* is of the quick-break type and is provided with the marble barrier *l* between the jaws to prevent arcing across. The switch *f* is used to disconnect the field of the alternator from the exciter and is provided with auxiliary carbon contacts to prevent burning the blades. The rheostat *g* is mounted on the back of the board and is operated by a hand wheel in front. This

rheostat is connected in series with the field of the alternator, so that the field current may be adjusted. The rheostat *h* is in the shunt field of the exciter and serves to regulate the exciter voltage. In many cases the rheostat *g* is not used, the field current of the alternator being increased or decreased by raising or lowering the exciter voltage by

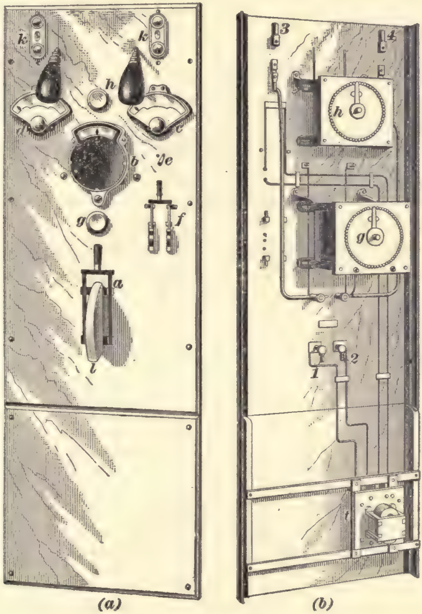


FIG. 60.

means of the rheostat *h*. It is best, however, to have the rheostat *g* also, especially if two or more alternators are excited by the same exciter, because it then allows the field current of each alternator to be adjusted independently of the others. The voltmeter *c* is connected to the machine through the potential transformer *t*, and a small voltmeter

switch *e* is placed in circuit so that the voltmeter may be cut out of circuit when not needed. The main fuses *k* are of the enclosed type previously described. No synchronizing device is needed on this board, as it is intended for a single machine only.

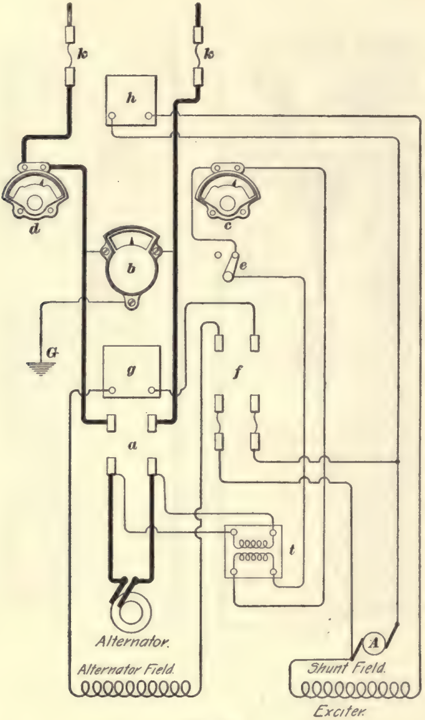


Fig. 61.

49. The rear view of the board will give a good idea as to the way in which the wiring is arranged. Heavy rubber-covered wire should be used for this work, and especial care

should be taken to see that everything is thoroughly insulated and neatly done. The leads from the alternator connect to terminals *1* and *2* and the line connects to terminals *3* and *4*. The potential transformer t is mounted on an iron framework at the base of the board, and when the lightning arresters are placed on the board, they are usually mounted on a similar framework rather than on the back of the board itself. This makes them stand out so that they do not crowd the wiring on the back. Fig. 61 shows the general scheme of connections on a board similar to that shown in Fig. 60. It will here be noted that on this board the current is led directly through the ammeter, because the current output of the alternator is not large. If a very heavy current were to be handled, a current transformer might be used in connection with the ammeter.

50. Switchboards for Parallel Running.—When alternators are operated in parallel, it is necessary to provide bus-bars running across the back of the board and to have the different machines arranged so that they may feed into these bus-bars. In fact, the arrangement is very similar to that shown in Fig. 57, with such modifications as are necessary to adapt the board to alternating current. Fig. 62 shows the connections for two three-phase machines arranged for multiple running, as used by the Westinghouse Company. The alternators are connected to the bus-bars through a high-tension switch in the ordinary way. Main fuses are here provided between the alternator and main switch, and these fuses may or may not be placed on the switchboard itself. The field excitation is carried out in the same way described in connection with Figs. 60 and 61, about the only difference being that field plugs c, c' are used instead of field switches. Three ammeters are provided for each generator, one in each leg of the three-phase system. In many cases, however, two ammeters only are used, as shown on the feeder circuit. T and T' are the potential transformers that furnish current to the voltmeters V, V' and also to the synchronizing lamps l, l'. The voltmeter

is also made to serve as a ground detector by using the plug switches *R*, *R'* and ground keys *k*, *k'*. The synchronizing

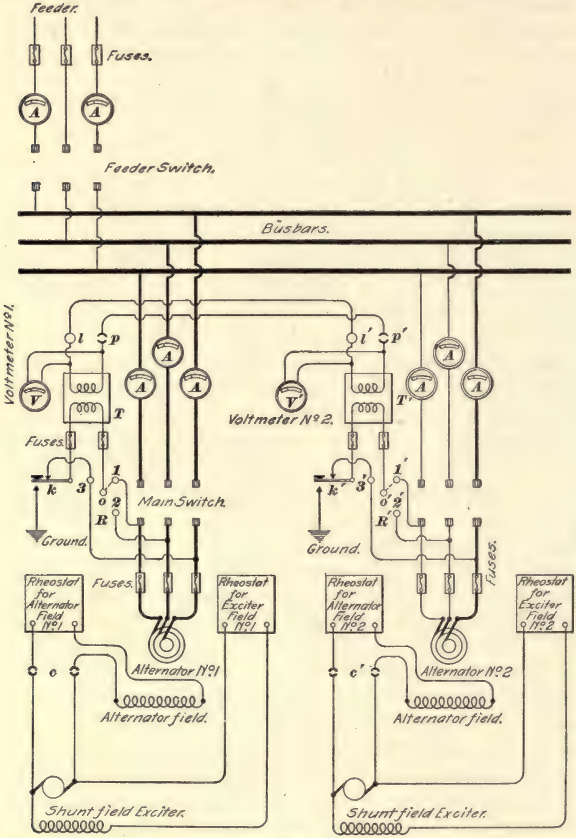


FIG. 62.

lamps are connected to the transformers by inserting plugs *p*, *p'*, and from the way in which the transformers are

connected, the lamps will be dark when the machines are in synchronism; by reversing the connections of one of the transformers, the lamps would be bright at synchronism. When the voltmeter or synchronizer is in use, the plug switches connect points *o'*, *1'* and *o*, *1*.

51. Sometimes when a number of alternators are operated in multiple, it is advisable to have their exciters arranged so that they may be operated in multiple also. If one exciter breaks down, the others may then supply the alternator that would ordinarily be supplied by the disabled machine. Again, in large plants, it is quite customary to supply all the alternators with their field current from one or two large exciters that feed into a pair of exciter bus-bars, from which the several alternators are supplied.

52. Running Alternators Separately.—In many lighting plants, the alternators are not run in multiple; in fact, special precautions are taken to see that there is no possibility of their being thrown in multiple. In such

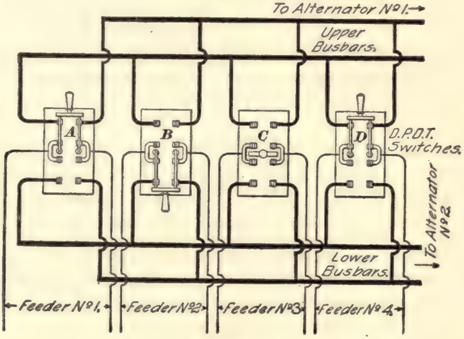


FIG. 63.

cases, they are arranged so that the load may be divided between them. This is usually accomplished by using double-pole, double-throw switches, as indicated in Fig. 63, when two alternators are used. The upper set of bus-bars

is connected to one alternator and the lower set to the other. The upper terminals of each feeder switch are connected to the upper bars and the lower terminals to the lower bars. The feeders are connected to the middle terminals as shown. When all the switches are up, the alternator No. *2* is not running, and the whole load is carried by No. *1*. As shown in the figure, circuits *1* and *4* are on alternator No. *1*, because switches *A* and *D* are both thrown up. Feeder *2* is on alternator No. *2*. Feeder No. *3* is cut out altogether, as the switch blades are standing straight out and the circuit is not connected to either pair of bus-bars. It is easily seen from the figure that any circuit or combination of circuits may be connected to either alternator and that there is no possible way in which the switches can be thrown so as to connect the alternators together. It is well, when arranging circuit-changing switches for separately operated alternators, to see that there is no possibility of the machines being thrown together, because if this is done, it is apt to lead to disastrous results. In plants where a number of alternators of different types and sizes are run, it is not usual to operate them in parallel, as there is always more or less trouble in doing so. In such cases, by using different sets of bus-bars and changing switches the load can be divided up properly.

POTENTIAL REGULATORS.

53. Where a number of feeders are supplied from a single dynamo, it is often necessary to have some means of raising or lowering the pressure on these feeders independently of each other. This matter has already been referred to in connection with direct-current plants where a booster is used in the circuit on which the pressure is to be raised or lowered. When alternating current is used, the pressure on the feeders can be easily raised or lowered by using what is known as a **potential regulator.** These appliances, while not usually placed on alternating-current switchboards,

are so closely connected with them that it is thought advisable to mention them in this connection. There are a number of different types of these regulators, but they all take the form of a special type of transformer, the primary of which is connected across the mains and the secondary is connected in series with the mains.

54. Stillwell Regulator.—One of the regulators that has been most largely used for lighting work is the **Stillwell regulator,** brought out by the Westinghouse Company. The action of this regulator may be explained briefly as follows: Suppose, in Fig. 64, that *A* is an alternator generating a pressure of 1,000 volts and that we wish to raise the pressure to 1,100 volts on the line. If we connect a transformer with its primary wound for 1,000 volts across the line and its secondary wound for 100 volts in series with the line, the 100 volts pressure of the secondary will be

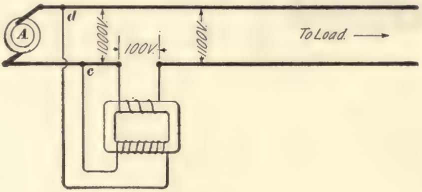


FIG. 64.

added to or subtracted from that of the alternator, depending on which terminals of the primary are connected to the mains. We will suppose that, with the connections as shown, the pressure is added and the voltage raised to 1,100 on the line. It is evident that if the terminals *c*, *d* of the primary were reversed, the pressure would be lowered by 100 volts. This simple arrangement would allow the pressure to be varied 100 volts either way. By dividing the secondary coil into a number of steps and providing the primary with a reversing switch, it is easily seen that this arrangement gives a means of varying the line voltage by steps through a considerable range. The Stillwell regulator

is made on this plan. Its general appearance is shown in Fig. 65, and Fig. 66 gives a diagram of connections. P is the primary of the transformer and S the secondary divided into a number of sections connected to the contacts of the switch M, as shown. A reversing switch b is placed in series with the primary, so that the pressure may be either raised or lowered. The contact arm N is split into two parts that make contact with the rings x, y and a choke coil r, i. e., a coil wound on a laminated iron core, is connected between these rings. This is done so that when the contact arm is passing from one of the contact points to the next, it will not short-circuit a section of the transformer, because the choke coil has a counter E. M. F. set up in it, thus preventing any rush of current. By tracing out the connections, it will be seen that they are equivalent to those shown in Fig. 64, the secondary S being in series with the line and the primary connected across the dynamo terminals. In Fig. 65, the regulating switch is seen mounted in the top of the case, together with the regulating and reversing handles.

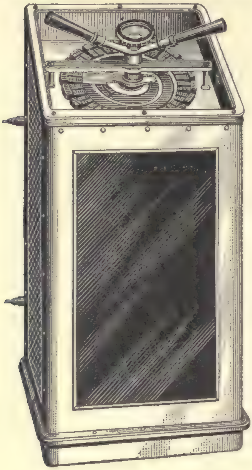


FIG. 65.

55. A number of regulators are in use in which the voltage in the secondary is varied by changing its position with regard to the primary, instead of cutting turns in or out. By having the secondary coil movable, it can be arranged so that the amount of magnetic flux passing through it can be varied, thus varying also the amount of the pressure added to or subtracted from the line. In other regulators, both the primary and the secondary coils are fixed, and a

movable core arranged so that the magnetic flux passing through the secondary can be made to vary. Both these methods afford a means of obtaining regulation by more

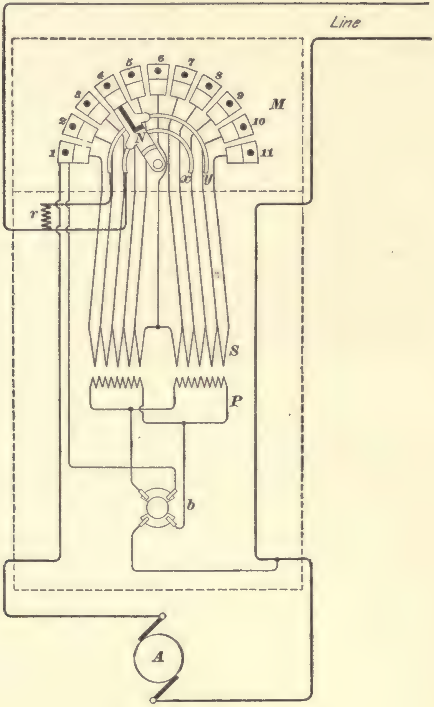


FIG. 66.

gradual steps than can be obtained with the Stillwell regulator. Potential regulators are usually placed at some point convenient to the switchboard, and in some cases the operating handles are mounted on the board itself and are geared, by chains and sprocket wheels, to the regulator.

USE OF STORAGE BATTERIES IN LIGHTING PLANTS.

56. Within the last 8 or 10 years, the use of storage batteries in connection with lighting plants has steadily increased, for the advantages to be gained from its use are so great that many of the largest stations in the country are now equipped with them. The load on all lighting plants is a variable one. During the day the load may be very light, while for a few hours in the evening it may run up to a large amount. As this period of maximum load is generally of not more than 2 or 3 hours' duration, it is evident that if no means of storing electrical energy were provided, the plant would have to be equipped so as to handle this maximum-current supply. The result would be that the larger portion of the machinery in the plant would be idle for the greater part of the day, and, therefore, would represent so much investment that would not be earning anything.

57. The storage battery, as an auxiliary in a lighting station, may be used in a number of different ways:

1. It may be used to carry the "peak" of the load; i. e., it may be used to help out the dynamos during the interval when the load is heavy, for it can be charged during the daytime, when the demand on the dynamos is light.

2. It may be used to carry the whole load of the station during intervals of light load, thus allowing the generating plant to be shut down for repair and inspection.

3. Batteries may be installed in substations in districts where a large amount of light is used. These batteries may be charged, during the daytime, from the central station, when the load on the main feeders is light, and thus, when the heavy load comes on in the evening, they are able to relieve the main feeders by taking up a part of the lighting service. The use of storage-battery substations, therefore, allows many more lamps to be supplied without the necessity of laying more feeders.

58. The above are the main uses to which a battery may be put, but there are many other incidental advantages. For example, the effect of a battery connected across the system is always to keep the voltage steady. By preventing fluctuations in voltage, a more satisfactory service to the consumer is secured and lamps of high efficiency may be used. Again, the electrical energy stored in a battery is instantly available. Throwing a switch or two will put it into service, whereas it always takes more or less time to get a dynamo and engine started, especially if the units are very large. This is an important consideration, especially in large plants, because it provides against an interruption of the service in case of a breakdown. Moreover, in large city stations, the load often rises very rapidly; it may increase several thousand amperes in a few minutes, due to a sudden turning on of lights because of a storm coming up, and it takes time to start the large generating units, even if they are kept turning over slowly so as to be in readiness.

59. Battery Taking "Peak" of Load.—Fig. 67 shows the load curve of a large city station and illustrates how a battery may be used to relieve the generating machinery of the peak of the load. Shortly after 4 P. M. the load begins to rise rapidly and the battery is thrown into service, as indicated by the double-shaded area. The dynamos do not have to deliver more than 13,000 amperes, although the current used on the system rises to about 20,500 amperes. If the battery were not used, it is evident that sufficient machinery would have to be installed to handle 20,500 amperes. The single-shaded areas represent the intervals when the battery is charging. By using a battery in this way, a station can, in very many cases, provide for an increased output without installing any additional dynamos, engines, or boilers, and at the same time it can work the existing machinery to the best advantage at or near its full capacity. Not only this, but the battery largely avoids the danger of overloads on the machinery, thus reducing the danger of breakdowns.

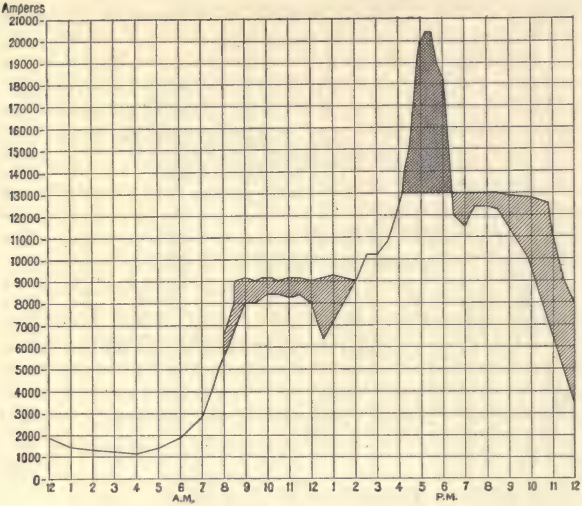

Amperes
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
A.M.
P.M.

FIG. 67.

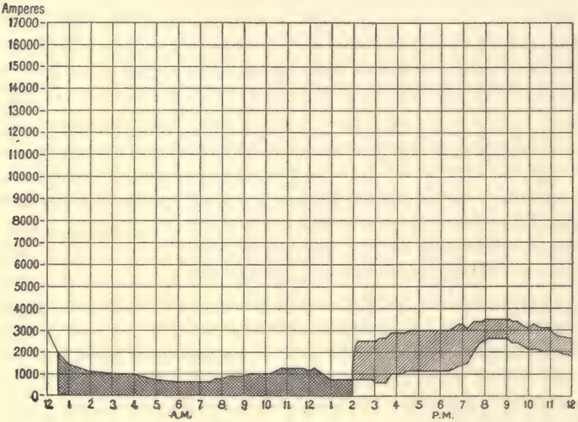

Amperes
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
A.M.
P.M.

FIG. 68.

60. Battery Carrying Whole Load on Station.—The curve, Fig. 68, shows the load curve for the same station as that shown in Fig. 67. This curve represents the load on a Sunday, and the load is very light compared with that shown in Fig. 67, because this station supplies a business district. It is seen that the generating plant is shut down altogether from 12.30 A. M. to 2 P. M., thus giving an opportunity for inspection or repair and allowing the station to be run with a small force of men. When the generators are started up at 2 P. M., the batteries are charged, as shown by the single-shaded area, thus allowing the generators in use to be run at more nearly their capacity, instead of on a light load only.

61. Battery Supplying Current From Substations. The use of storage batteries in this connection will be understood by referring to Fig. 69, where *A* represents the

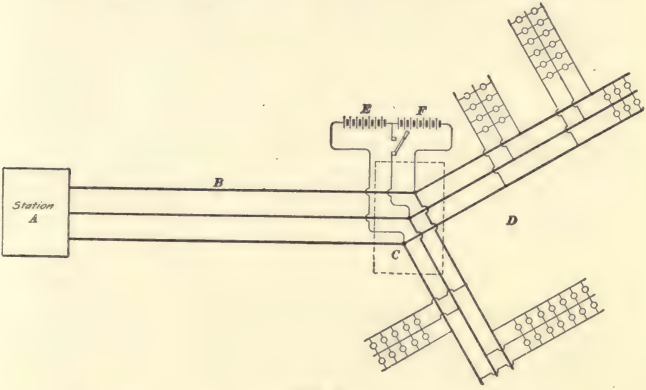


FIG. 69.

central station and *C* one of the substations. The three-wire system is here shown, as this is the one most largely used in distribution of this kind. The network of lamps fed from the substation *C* is represented by *D*. Now the load of lamps represented by *D* may be much in excess of what

could be supplied by the feeders *B* without causing a prohibitive drop. If, however, a battery *E F* is installed at *C* on each side of the system, it may be charged from the central station during the daytime and thus relieve the feeders at night, when the heavy load comes on. In other words, by using the battery, the feeders are worked at a more uniform rate throughout the day, instead of being lightly loaded the greater part of the time and heavily taxed when the peak of the load comes on. The use of the battery in substations not only equalizes the load on the dynamos, but also allows the maximum amount of service to be obtained from the feeders. In the large cities, the use of storage-battery auxiliary stations has become almost a necessity on account of the increasing business. They avoid the expense of additional feeders and allow the addition of a considerable load without necessitating the installation of additional machinery in the main station. Usually, the battery is connected across the outside lines, though a switch should be provided, as shown, so that the middle point of the battery may be connected to the neutral, if desired. A battery used at the end of a set of feeders regulates automatically and requires no boosting arrangement. When the load is light, the pressure at the center of distribution is high and the battery is charged. When the load is heavy, the pressure at the center of distribution falls off and the battery discharges.

BATTERY EQUIPMENT FOR LIGHTING PLANTS.

62. Capacity Required.—The capacity of the battery that should be installed in any given case must be determined wholly by local conditions, and depends very largely on the nature of the load that the station carries. It also depends on the way in which the battery is to be used. The only intelligent way to arrive at the capacity required is to lay out a number of load curves for the station in question, similar to that shown in Fig. 67. By doing this, the

number of ampere-hours that the battery should be capable of supplying can be approximated. In many cases, when installing plants of this kind, larger battery jars or tanks than those actually needed at the time are put in. The load is almost always sure to grow and the battery capacity may then be increased by simply adding a few more plates to each cell.

63. Type of Cell Used.—Storage cells designed for use in central stations must generally be of large size. For medium-sized cells, glass jars are used; but for the large types, the plates are mounted in strongly built wooden tanks lined with sheet lead and supported on glass or porcelain insulators. The chloride cell has been most largely used for this work in America. The plates used in these large cells are the same in construction as those described for the smaller ones. Fig. 70 gives a good idea as to the appearance and arrangement of some of the largest cells in use. Each cell here contains 87 plates $15\frac{1}{2}$ in. $\times$ 32 in. The lugs *l*, *l* on the plates are burned on to the channel-shaped pieces *c*, which form the connections between the cells; *d* is the lead lining and *e*, *e* are glass rods for separating the plates; *m*, *n* are the heavy copper conductors leading from the battery. The space occupied by a battery for a given output will depend on the way in which the cells are arranged, i. e., whether in one or two tiers. Generally, however, 1,000 kilowatt-hours can be stored per 100 square yards of space. The number of cells required in an installation will depend on the voltage to be supplied. In large central stations operating on the three-wire 110–220-volt system, about 80 cells are used on each side of the circuit, though the exact number of cells depends considerably on the range of voltage required to meet special conditions.

64. Regulation of Batteries.—In order to fully charge the cells, it is necessary to have a voltage somewhat higher than that on which the system is ordinarily run. Of course, this might be obtained by running the generators at a high voltage, but in most cases this is not practicable, because the

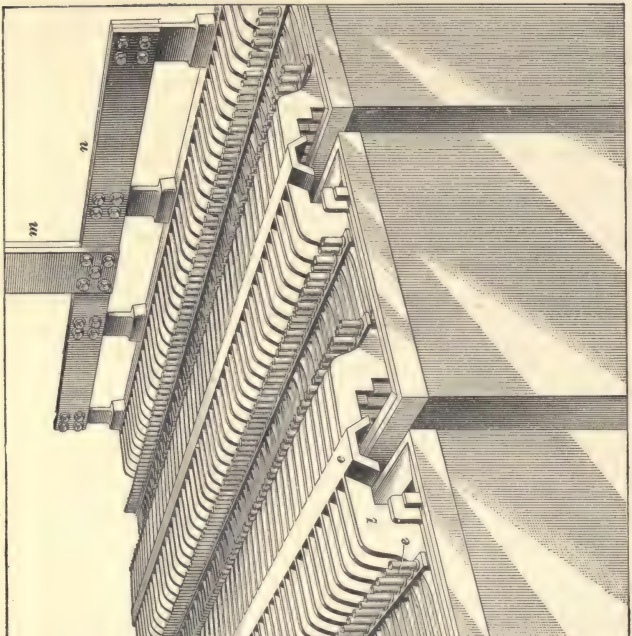


FIG. 70.

machines are generally used to supply current for lighting at the same time that they are charging the cells. In order, then, to raise the voltage on the battery, a "booster" is used when charging is going on. In lighting work, the booster is not generally used for regulating purposes, but simply to add enough pressure to the dynamos to enable them to charge the batteries. In railway work, where the load fluctuates very rapidly, the booster is so constructed as to make the battery discharge when the load is heavy and charge up when it is light. In lighting plants, the booster is usually shunt-wound or compound-wound and is driven by a motor. Fig. 71 shows one scheme of connections. Only the essential parts are here shown, so as to illustrate the principles involved without confusing the diagram with the various instruments and switches. For this reason, also, a simple two-wire system is illustrated. *G* is the generator supplying current to the lamp load *L*. *A* is the battery and *B* a number of cells at one end, from which connections are brought out to terminals *c*. A sliding contact *d* makes connection between contacts *c* and the bar *e*, so that by sliding *d*, the number of effective cells and, hence, the voltage of the battery may be increased or decreased as desired. This arrangement is known as an **end-cell switch**, and the

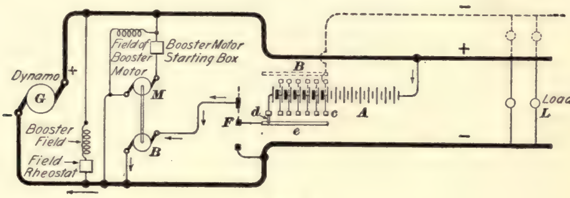


FIG. 71.

cells *B* are called **end cells.** *F* is a single-pole double-throw switch, by means of which the battery may be connected across *G* in series with the booster or directly across the line. In the figure, the switch is thrown up, as indicated by the dotted line, and the battery is being charged, because

the voltage generated in the booster armature is added to that of the generator. When F is thrown down, the battery A discharges into the line and the voltage may be regulated by means of the end-cell switch.

65. In lighting installations, the necessary regulation can easily be effected by means of end-cell switches, because the load does not fluctuate with great rapidity, as in railway work. In most large plants, two end-cell switches are provided in parallel, as indicated in Fig. 71, the second switch being shown dotted. This allows two different voltages to be taken from the battery, or in case of heavy loads the two switches may be operated together as one switch.

66. Since the end-cell switches must carry the current output of the battery, they must be substantially constructed and have contacts that are sufficiently heavy to carry the current without heating. The sliding piece d generally takes the form of a crosshead, which is moved by a screw that is driven either by a hand wheel or by a small electric motor controlled from the switchboard.

67. From the above it will be seen that the storage battery may be made a very valuable auxiliary, especially in large lighting plants. It must be remembered, however, that such batteries are expensive, and the question as to whether it will pay to put them in, in any given case, is a thing that must be looked into carefully. In large city stations, it no doubt does pay, as is shown by the large number installed. In smaller plants, where they cannot receive the same amount of skilled attention that they do in the larger ones and where the load handled is not, at best, very large, it may often pay better to install a larger generating capacity than to use a battery.

ELECTRIC LIGHTING.

(PART 3.)

ARC LIGHTING.

1. Introductory.—So far our attention has been confined to electric lighting by means of incandescent lamps, the methods of distributing the current, and the appliances used. We will now take up the subject of **arc lighting** and consider the special methods used in connection with it. The arc light, as before mentioned, was first exhibited in public on a large scale by Sir Humphry Davy, who used a large voltaic battery for supplying the current. After the dynamo had been invented and the cost of generating electricity thereby greatly reduced, the arc light came into use commercially. At first it was used mostly in lighthouses, but it was not long before it was used for street lighting, and it is now more generally used for such purposes than any other form of illuminant.

THE ARC.

OPEN ARCS.

2. General Features.—If two carbon rods attached to the terminals of a dynamo, as shown in Fig. 1, are first touched together and then drawn apart a short distance, say about $\frac{1}{8}$ inch, the current will continue to flow between the points and the carbons will become heated to an

exceedingly high temperature. An **electric arc** may be formed in this way between any pair of conducting terminals; for example, an arc might be formed between two copper or iron rods. In this case, however, the metals would be rapidly melted away; carbon, therefore, is always used because it is capable of standing the high temperature without being consumed too rapidly. The color of the arc depends on the material used for the electrodes; the arc formed between carbon is very brilliant, almost approaching sunlight. Violet rays are always present to some extent and give the arc light the well-known violet tinge that is often quite pronounced. An arc between copper electrodes is of a greenish tinge, while an arc between iron terminals is accompanied by a brilliant shower of sparks. An arc may be formed between carbon and copper or carbon and platinum, the carbon in both cases being used for the upper or positive **electrode,** as the terminals are often called, and the copper or platinum for the lower electrode. This arrangement has been used in a few isolated cases. For example, an upper positive carbon and lower copper electrode have been used in one form of locomotive headlight. It is important when this arrangement is used to see that the upper carbon is connected to the positive pole of the dynamo, so that the current flows from the carbon to the copper. If it flows the other way, the copper or platinum electrode will soon be burned away.

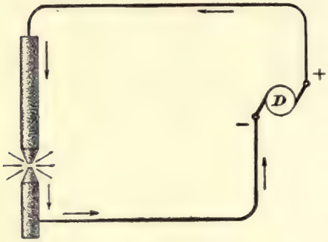


FIG. 1.

3. After the carbons have been separated for a time they take on the appearance shown in Fig. 2. This represents an open arc, or an arc formed in the open air, as distinguished from one that is formed in a confined space

where very little oxygen is present. The term **arc** came to be used because of the small bow-shaped or arc-shaped flame that may be seen playing between the carbon points. This flame is the arc proper and consists of incandescent carbon vapor that conducts the current across from point to point. This flame, or arc, of carbon vapor acts in the same way as a wire carrying a current. If a magnet is brought near it, the arc will be forced over to one side, and if the magnet is strong enough, the arc will be stretched out until it is broken. Also, the arc itself, under ordinary working conditions, will be surrounded by a magnetic field, and it is, no doubt, this field that causes the arc to assume the bow shape. The flame keeps shifting around the points as the carbons burn away.

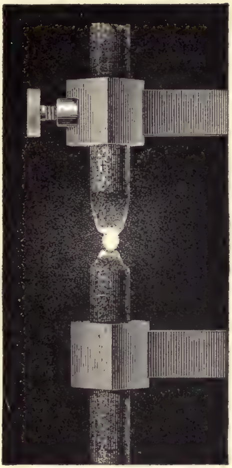


FIG. 2.

4. Direction of Current.—The shape of the carbon points depends on the direction in which the current flows. In Fig. 1, the top carbon is supposed to be the positive one, so that the current flows from the top to the bottom, as is nearly always the case in practice. Fig. 3 shows a section of the carbons, and it will be noticed that the upper or positive one becomes hollowed out slightly, as shown at *a*, while the lower one becomes pointed. The hollow *a* is known as the **crater,** and is the seat of the greater part of the light given out by the arc. When the arc is in

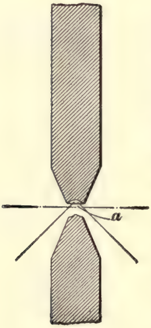


FIG. 3.

operation, the carbon becomes volatilized at the crater, and this vapor of carbon conducts the current to the negative carbon. Although the temperature of the negative carbon is high, it is not nearly so high as that of the vapor and, hence, the latter is condensed on the negative tip forming the point or else is thrown off. Only a portion of the vapor is so condensed; part of it combines with the oxygen of the surrounding air and the burning carbon monoxide may be seen surrounding the arc as an envelope of bluish flame, similar to that which appears over the coal in an ordinary coal stove. The positive carbon wastes away approximately twice as fast as the negative, as it is maintained at a much higher temperature.

5. Temperature of the Arc.—The temperature of the electric arc is the highest that has yet been produced by artificial means. Its exact temperature is difficult to determine, but it is estimated to be about 3,500° C. Some idea as to what this means may be obtained when it is known that a temperature between 1,700° and 1,800° C. is sufficient to melt platinum, the most difficult of all the metals to melt. The high temperature of the arc has been made use of in connection with various kinds of electric furnaces. The carbon in the crater is vaporized; hence, the temperature attained must be that of the boiling point of carbon. An increase in the current does not increase the temperature any, but it does increase the size of the crater and, hence, the total amount of light given out. If very powerful lamps are required, large carbons and heavy currents are used, so as to get a large crater. This is done in lamps used for searchlights. For ordinary commercial street lighting, the carbons are usually about ½ inch in diameter, though sometimes larger carbons are used to make the lamps burn longer.

6. Voltage of the Arc.—If the voltage across the terminals of an ordinary open-arc lamp is measured, it will be found that it usually lies between 40 and 50 volts, depending

on the length of the arc; 45 volts may be taken as a fair average. This total voltage may be looked upon as made up of three parts: (*a*) That necessary to overcome the resistance of the carbons and the parts of the lamp mechanism through which the current has to flow; (*b*) that necessary to overcome the resistance of the carbon vapor between the electrodes; (*c*) that which multiplied by the current represents the energy necessary to volatilize the carbon.

The E. M. F. necessary to overcome the resistance of the carbons and lamp mechanism is not very large; in most lamps it will not be more than 5 or 6 volts, of which 3 to 3.5 may represent the drop in the carbons and the balance is in the mechanism and various contact resistances.

The E. M. F. necessary to overcome the resistance of the arc proper is also small, but depends to a certain extent on the length of the arc. In most cases it will not be more than 5 or 6 volts.

Since the voltage across the lamp is, say, 45 volts and the combined drop due to the resistance of the carbons, lamp mechanism, and arc proper is, approximately, 10 volts, it follows that the balance (about 35 volts) multiplied by the current represents the number of watts expended in bringing the carbon up to the boiling point and causing it to volatilize. This voltage is often spoken of as the counter E. M. F. of the arc, but this term is not so commonly used as it once was. It is evident that quite a large amount of energy must be expended to bring the carbon up to the boiling point, and it is now generally admitted that the large balance of voltage required over and above that necessary to overcome the various resistances is a consequence of the power necessary to volatilize the carbon. The above values of the voltage are fair average values for open-arc lamps operated with direct current, but they may vary somewhat with different makes of lamp. The actual voltage across the arc is continually varying when the lamp is in operation, but in a well-adjusted lamp it should not vary through wide limits.

7. Current. — Ordinary direct-current open-arc lamps are usually operated with current ranging from 6 to 10 amperes. Very common values for the current are 6.6 amperes for lamps giving 1,200 nominal candlepower and 9.6 amperes for those giving 2,000 nominal candlepower. The exact value of the current is different in lamps of various makes, but whatever it may be, it is essential that it be maintained at a constant value if the lamps are to work properly. If the current becomes larger than that for which the lamps are designed, they will overheat and the carbons will flame badly and the service will be generally unsatisfactory. Open-arc lamps may also be operated with alternating current, but they are not as satisfactory as those using direct current either as regards light-giving properties or general performance. In the case of the open alternating-current arc, both carbons become pointed or have very small craters, so that the light is thrown upwards much more than with the direct-current lamp. Also, since the current flows alternately in opposite directions, the rate of consumption of the two carbons is more nearly equal. Fig. 4 shows the general form of the carbons with an open alternating-current arc.

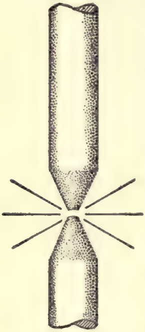


FIG. 4.

ENCLOSED ARCS.

8. General Description.—So far all that has been said with regard to the electric arc relates to arcs set up between carbon points placed in the open air. Within a comparatively recent date, **enclosed arcs** have been coming into extensive use, and bid fair to take the place of the open arc altogether. The enclosed arc differs from the ordinary open arc in that it is surrounded by a small globe that practically excludes the air. Fig. 5 shows the general arrangement of the carbons and the enclosing globe. *G* is a glass bulb from

5 to 6 inches long and about 3 inches in diameter, provided with an opening at each end. The lower end is held by a holder C and the lower edge E of the globe is ground so that but little air can get in at the bottom. In some makes of lamps an asbestos washer is used between the lower edge of the globe and the holder, to make a tight joint and distribute the strains on the glass. The lower carbon B is clamped in the holder C. The top of the bulb is ground smooth and supports a **gas cap** P with a hole in the center, through which the positive carbon passes. This plate is not fastened to the bulb, but is free to move about a little, and the hole in the center is just large enough to allow the positive carbon to move up and down freely. It is necessary to have the plate itself free to move, in order to get the carbons in line and prevent binding due to any slight irregularity in the carbon. Since the top of the glass and the lower surface of the plate are ground plane, little air can get in between them, and the only place where much air can enter the bulb is at the hole in the center of the top plate, through the small space between the carbon and the plate itself.

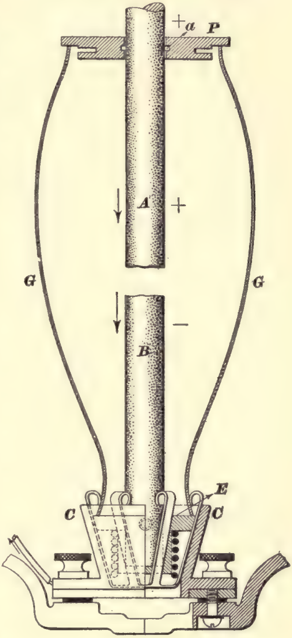


FIG. 5.

In the plate shown in the figure, there is an annular groove a around the carbon. This leaves less surface for the carbon to rub against and affords a space in which

eddies are formed by the hot air passing up, thus further tending to keep out the cold air.

The above is intended merely to illustrate the general arrangement of the enclosed arc. The methods of holding the globe and the arrangement of the lower carbon holder differ in the various makes of lamp. A number of different styles of gas cap *P* are also in use, and the satisfactory operation of the lamp depends to a considerable extent on the design of this part.

9. As soon as the carbons are drawn apart an arc is formed, as in the ordinary lamp, but the oxygen in the globe is soon burned out and the gases present become rarefied, because the heat of the arc causes them to expand and pass out. The globe is not air-tight and there is always a small amount of oxygen present. This, however, is not enough to cause anything like the rapid combustion that takes place in the case of the open arc. The arc practically burns in a hot atmosphere of nitrogen, carbon monoxide, carbon dioxide, and a small amount of oxygen. This latter is just about sufficient to combine with what carbon is thrown off and prevent its being deposited on the glass. If a lamp is in good condition, it will burn anywhere from 80 to 150 hours, depending on the design, without renewing the carbons. The bulb in time becomes coated with a light-colored deposit, sometimes mixed with a little carbon, which comes principally from impurities, such as silicon. This deposit does not cut off the light to any great extent if it is not allowed to become too thick. If the current passed through the lamp is excessive, the globes will become blackened or even melted. It is not usually advisable to burn these lamps more than 120 hours, as the deposit becomes so thick as to cut off a considerable amount of light.

10. Consumption of Carbons.—One of the most striking features of the enclosed-arc lamp is the slow consumption of the carbons. This is, of course, due to the absence of oxygen in the enclosing chamber. With the ordinary open arc the positive carbon is burned at the rate of

about 1½ inches per hour, while in an enclosed-arc lamp the consumption varies from .07 to .08 inch per hour. Enclosed-arc lamps may, therefore, be made to burn a long time without trimming; some have even been made to burn as long as 200 hours. This is one of the features that has led to the extensive introduction of this type of lamp. As in the open arc, the negative carbon of the direct-current enclosed arc burns about half as fast as the positive carbon; with alternating current, the consumption is more nearly equal.

11. Voltage and Current.—If the carbons of an open arc be pulled apart a distance more than enough to give from 40 to 45 volts across the arc, they will flame badly. On the other hand, the enclosed-arc lamp is operated with a long arc, about ⅜ inch, and it burns quietly. If a short arc is used in the enclosed arc, it is found that soot or carbon is deposited to such an extent that the lamp becomes useless; long arcs are, therefore, essential in these lamps. This allows them to be operated at a high voltage, and many of them take from 70 to 80 volts across the arc. They usually operate with a smaller current than the open-arc lamps, some of them taking as low as 2½ to 3 amperes. The advantage of using a high voltage and small current will be seen when we come to consider the operation of lamps in parallel on constant-potential circuits. Enclosed-arc lamps have also been built to operate on 220-volt circuits. Such lamps burn with a very long arc and are not quite as efficient as the ordinary 110-volt lamp, to which the above figures refer.

12. Character of Enclosed Arc.—Fig. 6 gives a general idea of the appearance of a direct-current enclosed arc. The student should compare this with Fig. 2. In the enclosed arc the carbons are separated by a wide gap, but the principal difference is that they do not take on the pointed shape. The ends of the carbons remain nearly flat and the arc keeps continually shifting around over the ends. The flat shape of the ends is, no doubt, due largely to this tendency of the arc to shift around. The light given out is

soft and tinged with violet rays, having much less of the dazzling appearance so well known in connection with the ordinary arc. In the alternating-current enclosed arc, the lower and upper carbons are of about the same temperature and the light is thrown up more than with the direct-current arc. The carbons have, however, the flat-ended appearance and the arc shifts around even more than that of the direct-current enclosed arc.

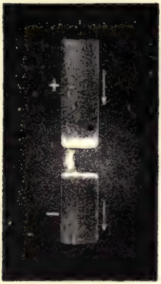


FIG. 6.

13. Open Versus Closed Arcs.—There has been, and still is, a great deal of discussion as to the relative advantages of open and enclosed arcs, especially for street lighting. For interior illumination, there can be little question as to the superiority of the enclosed arc. The light is very much softer and steadier and, in addition, the fire risk is less, because a large outer globe is usually provided in addition to the small enclosing globe. For street lighting, their advantages have not been quite so pronounced. Open-arc lamps have now been used for so many years for this work and have, on the whole, given such good satisfaction that they are not so easily replaced as in the case of interior lighting. At the same time, it is no doubt true that enclosed-arc lamps are ousting the older style open-arc lamps even for street-lighting work, and it is claimed that a considerable saving is effected by the change, principally because the cost of trimming and the cost of carbons is less. Of course, there is the renewal of broken inner globes in the case of the enclosed lamp, and also the additional work of keeping these globes clean, but even taking these items into account, the advocates of the enclosed-arc lamp for street lighting claim that a saving of $8 to $10 per year per lamp can be effected.

Wherever lamps must be operated by alternating current, the enclosed-arc lamp is extensively used and practically has the field to itself. The alternating-current open-arc

lamp never proved a decided success. It usually made a loud humming noise and could not compete well with the direct-current arc lamp as an illuminant. The alternating-current enclosed-arc lamp has, however, been brought to such a state that it gives satisfactory service. The mechanism has been designed so that little noise is possible, and the enclosing of the arc prevents the humming of the arc itself from being loud enough to be objectionable. While, however, the alternating-current enclosed-arc lamp is much superior to the alternating-current open-arc lamp, it can hardly be said that it is capable of giving as good all-around service as the direct-current enclosed-arc lamp. No doubt, still further improvements will be made that will put it more nearly on a level with its direct-current rival.

ARC-LIGHT CARBONS.

14. Arrangement of Carbons.—In nearly all the lamps used for ordinary purposes, the carbons are arranged vertically, one above the other, as shown in Fig. 2. When arranged in this way, the top carbon should always be the positive one when direct current is used, otherwise the crater will be formed in the bottom carbon and most of the light will be thrown up instead of down. When lamps are first connected up, they should be allowed to burn for a short time, and if the crater makes its appearance in the bottom carbon, the connections to the lamp terminals should be reversed. Of course, with alternating current it makes no difference how the lamp is connected in circuit, as the current is continually reversing anyway and both carbons burn alike. It is an easy matter to tell when a direct-current lamp is correctly connected. Allow the lamp to burn for a short time, then switch it off and see which carbon remains bright the longer. The positive carbon is much hotter than the negative, hence the negative carbon is the one that becomes dull first.

15. For use in stereopticons and other projection apparatus, the carbons are often inclined at an angle, as shown

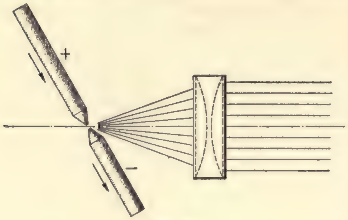


FIG. 7.

in Fig. 7. The object in doing this is to allow more of the light from the crater to reach the lenses. In searchlights a similar arrangement is used, only the carbons are often slanted the other way and the light is reflected from a parabolic reflector or Mangin mirror, as shown in Fig. 8, which shows the arc placed at the focus of a parabolic reflector *M*. The rays of light upon striking the mirror are reflected out parallel to each other, and as they are thus kept bunched together the light may be made to penetrate long distances. A small concave reflector is usually placed, as

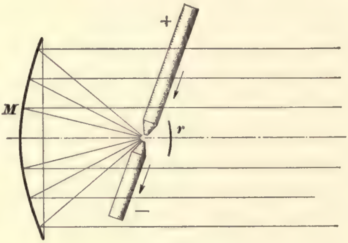


FIG. 8.

shown at *r*, to throw the rays of the arc that would ordinarily pass outwards back towards the main reflector.

A parabolic ground-glass silvered mirror is used in the

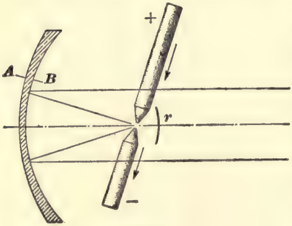


FIG. 9.

United States Navy, but for ordinary commercial work the Mangin mirror is used, as it is cheaper and easier to make. It is a glass mirror having two spherical surfaces *A*, *B* of different radii, as shown in Fig. 9. The back surface *A* is silvered and the rays are reflected

from it. As the glass is thicker near the edges than it is in the middle, the rays are there bent or refracted more than they are at the center, and by making the mirror of the proper dimensions it can be made to reflect the rays in a horizontal direction and give practically the same effect as the parabolic mirror.

Fig. 10 shows another arrangement of carbons that is used in searchlights. In this case the positive carbon is larger than the negative, and both carbons are arranged horizontally. The crater, therefore, points directly at the mirror. This is the arrangement now most extensively used in America both for naval and commercial work.

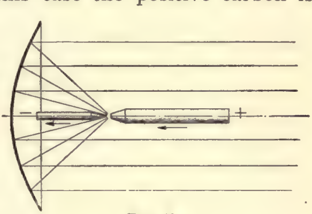


FIG. 10.

In all cases where arc lamps are used in connection with mirrors or lenses for projection work, it is essential that the arc be kept in the focus of the mirror or lens. The lamps must, therefore, be arranged to move the carbons towards each other as they are consumed, and they must do this in such a way that the position of the arc will not change. A lamp that does this is known as a **focusing lamp.** For ordinary lighting, it is not essential that the arc be kept in one place, so that the lower carbon is nearly always fixed and the arc maintained by allowing the upper one to move downwards as the carbon is consumed.

Fig. 11 shows a rather peculiar arrangement that is used for stereopticon lamps. Here the carbons are arranged at right angles to each other. The lamp mechanism moves B out in a horizontal direction, and C upwards as they burn away, so that the arc is always maintained in the same position at a. The position of C keeps it from interfering with the lens l, and

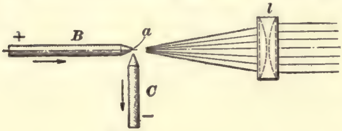


FIG. 11.

allows the greater part of the crater in the end of B to be exposed.

16. Composition of Carbons.—Carbons used for ordinary open-arc lamps in America are composed principally of petroleum coke. This is made from the residue left from the distillation of petroleum. It is ground up and mixed with a binding material, such as tar, or a similar substance, and is then molded into rods. Sometimes the rods are made in molds under a heavy pressure, but more frequently they are made by forcing the material through dies. The rods are then gradually dried and afterwards baked or fired at a high temperature. Gas-retort carbon has also been used for the manufacture of arc-light carbons, the exact composition used varying with different makers.

17. For enclosed-arc lamps a very much finer quality of carbon is required than for the open-arc lamp. If the carbons used in these lamps are at all impure, the impurities become volatilized and are deposited on the inner globe. Enclosed-arc carbons are, therefore, made principally of lampblack, which is practically pure carbon, and are considerably more expensive than the ordinary carbons made from petroleum coke. They must be straight and of uniform diameter, otherwise they will not pass through the cap of the enclosing globe properly.

FIG. 12.

The tendency of the arc to wander around the ends of the carbons has already been mentioned. This is especially the case with alternating current, and in order to hold the arc in the center, cored carbons are used. Fig. 12 shows a cored carbon; it is so called from the core a running through it. A small hole runs through the center of the carbon, and this is filled with a much softer material than the surrounding part. Some makers use cored carbons for both the + and the − electrodes of alternating-current lamps, while others use them for the + electrode only.

Cored carbons are used more particularly with alternating-current lamps, as the plain carbons usually give satisfactory service with direct current. Searchlights are almost wholly operated by direct current and the positive carbon is generally cored, as it is important to keep the arc in one place as much as possible.

Whatever kind of carbons may be used, it is essential that they be as pure and as uniform in quality as possible. If many impurities are present, they may interfere seriously with the quality of the light. Of course, impurities are especially bad in the case of the enclosed arc on account of the deposit caused on the inner globe, but even in the open arc they are objectionable because they volatilize at a much lower temperature than the carbon and thus tend to lower the temperature and light-giving properties of the arc. Hard spots in the carbons will cause uneven burning and carbons that are too soft are apt to flame badly. Hard spots will also give rise to hissing.

Carbons used for open-arc lamps are usually electroplated with a thin coating of copper. This increases their conductivity and makes them burn more uniformly and last longer.

PHOTOMETRY OF THE ARC LAMP.

LIGHT DISTRIBUTION.

18. The light given out by an incandescent lamp is fairly uniform in all directions, assuming, of course, that the lamp has no shade on it. On the other hand, the light given out by an arc lamp with a clear globe varies greatly in different directions. Since the manner in which an arc lamp distributes its light is of the greatest importance, it will be well to examine the peculiarities of some of the more important types. It will not be necessary here to go into the methods of measuring the light intensity. It is usually done by means of a Bunsen or similar photometer, with the

arc lamp so arranged that its candlepower may be measured in any direction.

19. Before going into the subject of light distribution a few points with regard to globes may not be out of order Ordinary open-arc lamps used for street lighting are generally provided with clear globes. A clear globe will cut off from 6 to 10 per cent. of the light, and if it is dirty it will cut off more. Sometimes opal globes are used, especially if the lamp is used for interior work. An opal globe softens the light and does away with the sharp shadows that are always present with a clear globe. In other words, an opal globe alters the distribution of the light considerably and avoids the deep shadows underneath the lamp. At the same time, a globe of this kind cuts off from 30 to 40 per cent. of the light; in fact, if the globe is very milky it may easily cut off 50 or 60 per cent. In the case of the enclosed-arc lamp we have, in addition to the outer globe, the inner globe, and hence the amount of light cut off is somewhat increased. Reflectors are used much more largely with the alternating-current arc lamp than with the direct arc, because the former tends to throw its light to a greater extent above the horizontal, and by using the reflector this light can be thrown downwards and utilized.

20. Open-Arc Direct-Current Lamps.—The distribution of light from an ordinary open-arc lamp is about as shown in Fig. 13. This represents the variation in the intensity of the light at different angles above and below the horizontal line passing through the arc that is located at *a*. The distance from *a*, measured along the radius at any given angle, is proportional to the candlepower of the lamp when viewed from that position. For example, the light reaches its greatest intensity at a point about 45° below the horizontal and then rapidly diminishes on both sides of this point. Directly above or below the arc there is, of course, little or no light, as the arc is obscured by the frame of the lamp and the carbons themselves. The open arc

throws out comparatively little light in the horizontal direction, and the quantity of light thrown upwards is small. It is thus seen that the plain open-arc lamp using a direct current as it stands, without any reflector and with simply a clear-glass globe, gives a good distribution of light for street lighting because, on account of the formation of the crater in the upper carbon, it throws the bulk of its light

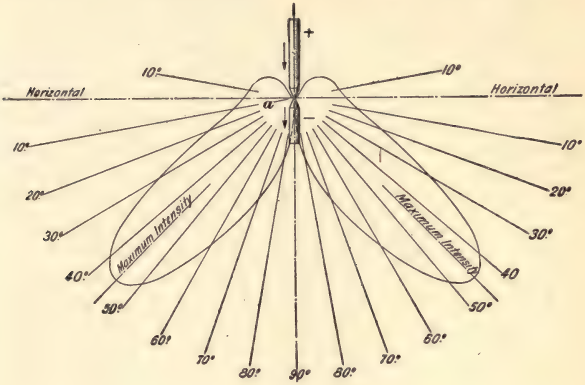


FIG. 13.

downwards at an angle of about 45°, where it is most needed. This is one of the reasons why the direct-current open-arc lamp has proved so successful for street lighting. If the deep shadows directly under the lamp are objectionable, they may be softened by using a clear globe with the lower half ground.

21. Open-Arc Alternating-Current Lamps. — The distribution from an alternating-current open-arc lamp is not of much practical importance because these lamps are now seldom used. It is, however, instructive to compare it with Fig. 13. Fig. 14 shows the general distribution from an alternating-current open arc, as determined by Uppenborn. It will be noticed that a great deal of the light is

thrown above the horizontal. This is because the two carbon points are alternatively positive and negative, so that both become heated to nearly an equal amount. Such a lamp, to be effective for street lighting, should be provided with a reflector to throw the light down where it is wanted.

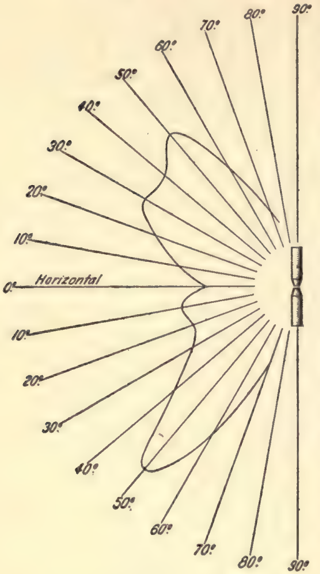


FIG. 14.

The curves shown in Figs. 13 and 14 represent average distributions. It must be remembered that the arc always shifts around more or less, and hence the shape of the distribution is constantly changing and makes the measurement of the light given out in the various directions an exceedingly difficult matter. The curves will, however, enable the student to note the marked difference in the light distribution of the alternating-current open arc as compared with the direct-current open arc.

22. Enclosed-Arc Direct-Current Lamps. — There has been a great deal of discussion regarding the light-giving properties and efficiency of the enclosed arc as compared with the open arc. The data here given is abstracted from a report of a committee of the National Electric Light Association on tests made by Prof. C. P. Matthews, and is probably as unbiased as any obtainable. Fig. 15 shows the average of curves from direct-current 110-volt enclosed-arc lamps used on constant-potential

circuits. Curve *A* shows the distribution when the lamp is provided with an opalescent inner globe only; there is no larger outer globe. The student should compare this curve with that shown in Fig. 13 for the open arc. It will be noticed that with the enclosed arc, the light is of fairly large intensity through a considerable angle below the horizontal. In this case, the maximum value is approximately 360 candle-power and occurs about 30° below the horizontal. This is considerably less than the intensity given by an open arc, at about 40 to 45° below the horizontal, but the light from the latter falls off very rapidly on each side of the maximum point, whereas in the enclosed arc it is fairly well maintained through a considerable angle. Curve *B* shows the distribution when the lamp is provided with a clear outer globe in addition to the inner opalescent globe. The effect is to slightly cut down the intensity as a whole. Curve *C* shows the effect of using an outer opalescent globe. It is easily seen that the effect is to make the light approximately uniform in all directions at the expense of greatly cutting it down.

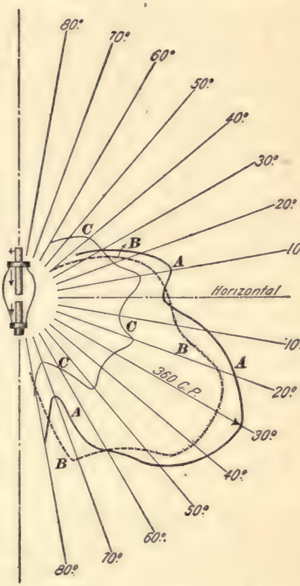


Fig. 15.

The distribution of light from an enclosed-arc lamp is subject to considerable variation. It depends to some extent on the shape of the enclosing globe and also on the thickness of deposit on it. It also depends on the position of the arc in the enclosing globe.

23. Enclosed-Arc Alternating-Current Lamps.—The direct-current lamp gives a better distribution for street lighting than the enclosed-arc alternating-current, and, on the whole, the latter is not quite as efficient as the direct-current. If, however, full benefit is to be obtained from the light given by the alternating-current enclosed arc, a reflector of some kind must be used. This is shown by the curves in Fig. 16. Curve *A* represents the distribution from an enclosed-arc alternating-current lamp that has an opalescent inner globe and a clear outer globe. It will be noticed that a large quantity of light is thrown above the horizontal, as in the case of the open-arc alternating-current lamp. Curve *C* shows the distribution when the same lamp is provided with a reflector. The curves show how the light that would ordinarily be thrown upwards and, hence, would be of little or no use for street illumination, is made available. Thus equipped with a reflector, the alternating-current arc makes a better showing against the direct-current. The alternating-current enclosed arc equipped with a reflector is rapidly finding favor as a street illuminant, though it may not be quite as efficient as the direct-current arc; its use in many cases so simplifies the outfit required at the station that the slight difference in the efficiency of the lamps themselves is more than made up.

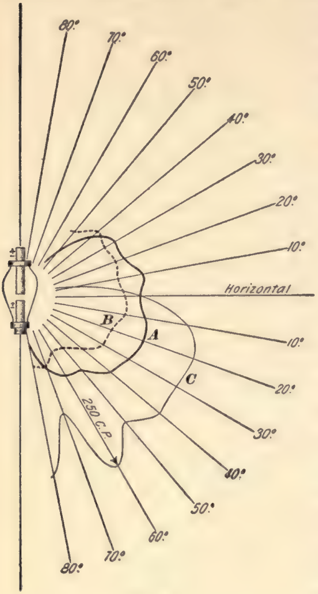


FIG. 16.

This will be more apparent later when we come to consider the various systems of supplying lamps with current. In Fig. 16, curve *B* shows the distribution given by an alternating-current enclosed-arc lamp when used with opalescent inner and outer globes.

CANDLEPOWER OF ARC LAMPS.

24. The candlepower of an arc lamp is a rather indefinite quantity. In making comparisons between different lamps, the only way to make such a comparison that is at all fair is to take the mean spherical candlepower of the lamps, i. e., what their candlepower would be if it were equal in all directions, instead of varying, as indicated by the curves just shown. In comparing incandescent lamps, it is usually sufficient to compare their mean horizontal candlepower as obtained by spinning the lamp, but in the case of an arc lamp the distribution is so irregular that the mean spherical candlepower must be taken. Again, the candlepower of an arc lamp as given out in the various directions is a difficult thing to measure accurately with the photometer. The arc always keeps shifting, and the intensity of the light is subject to such variations that a large number of settings of the Bunsen screen must be made to obtain anything like average results.

25. In the early days of electric lighting it was customary to speak of the ordinary lamp as giving 2,000 candlepower or 1,200 candlepower. The candlepower of these lamps was not nearly as high as this. It is barely possible that under exceptional conditions the light given out in the *maximum direction* might have reached these figures, but the average candlepower was nowhere near 2,000. About 375 to 450 would be nearer the mark. This old rating gave rise to a great deal of trouble, as customers were often told that the lamps should give 2,000 candlepower and that the lighting companies were not living up to their

contract. It has become customary, therefore, to specify arc lamps as taking so many watts instead of supplying a certain number of candlepower. This is, generally, more satisfactory, because the watts can be measured at any time, to see if the contract is being lived up to. The lamp formerly rated at 2,000 candlepower has thus come to mean one that is supplied with 450 watts, and a 1,200 candlepower one that is supplied with 300 watts. The ratings 2,000 and 1,200 candlepower should never have been applied to these lamps in the first place, as they have absolutely no meaning. As has been stated, the mean spherical candlepower of an ordinary direct-current open arc is, generally, somewhere between 375 and 450 candlepower. The mean spherical candlepower represented by curve *A*, Fig. 15, is about 223; curve *B*, 181; curve *C*, 155. For the alternating-current lamps, represented by Fig. 16, the mean spherical candlepower for curve *A* is about 140; for curve *B*, 114.

26. Power Consumption per Candlepower. — The number of watts that must be supplied to the terminals of an arc lamp per mean spherical candlepower will depend on the construction of the lamp and on the conditions under which it is used. For example, when direct-current lamps are operated on 110-volt direct-current circuits, it is necessary to have a resistance in series to take up the voltage over and above the 80 volts required by the arc, and even if the line voltage were suited to that of the arc, a resistance would still be necessary to make the lamp regulate properly, as will be explained later. The waste in this resistance may amount to as much as 140 or 150 watts, and this lowers the general efficiency of the lamp. When lamps are operated in series, this resistance is not necessary and the waste in the lamp is less. An ordinary series open-arc lamp requires about 1.2 watts per spherical candlepower. A direct-current enclosed arc requires about 1.8 watts per spherical candlepower, not counting the power lost in the resistance. If a resistance is used, as in the case

of the lamp operated on 110-volt direct current, the power consumption per candlepower will be 2.3 to 2.4 watts. For example, the lamp represented by curve A, Fig. 15, took 4.9 amperes at 110 volts or 539 watts, of which 147 watts were wasted in the resistance and 392 watts taken up at the arc. The lamp gave about 223 mean spherical candlepower; hence, the total number of watts per candlepower was $\frac{539}{223} = 2.4$. Not counting the loss in the resistance, the watts per candlepower would be 1.8, nearly.

The alternating-current enclosed-arc lamp requires about 2.4 watts per spherical candlepower, not counting the energy lost in the lamp mechanism. If an alternating-current lamp is run from constant-potential mains, the excess voltage can be taken up by a reactance, or choke coil, which wastes much less energy than a resistance. The energy wasted in the mechanism of a constant-potential, alternating-current arc lamp will not be more than half that of the direct-current lamp using a resistance. If we include the power lost in the mechanism in both cases, the alternating-current, constant-potential enclosed arc would require 2.45 watts, as against 2.3 watts required by the direct-current arc. If we use a shade on the alternating-current arc, the power consumption per candlepower delivered below the horizontal becomes much less; but in comparing the different lamps, we must take them all under the same conditions as nearly as possible.

27. The above figures are intended to give a general idea as to the efficiency and illuminating power of the various kinds of lamps, and represent average conditions. Of course, lamps may be met with that will vary considerably from the above. If we take an enclosed-arc lamp taking 450 watts and compare it with an open-arc lamp taking the same amount of power, we will find that the open-arc lamp will give a somewhat brighter illumination on the street. Notwithstanding this fact, the public, as a rule, does not object to the enclosed arc being substituted

TABLE I.

POWER CONSUMPTION OF ARC LAMPS.

Type of Lamp.	Total Watts Consumed.	Watts Consumed in Resistance or Choke Coil.	Watts at Arc.	Mean Spherical Candlepower.	Total Watts per Mean Spherical Candlepower.	Watts at Arc per Mean Spherical Candlepower.
Series open arc 2,000 nominal candlepower about 9.6 amperes at 50 volts	460–480		450	375	1.3	1.2
Direct-current enclosed arc 110 volts 4.9 amperes, opalescent inner globe, no outer	539	147	392	223	2.4	1.8
Same with opalescent inner and clear outer globes	539	147	392	181	2.9	2.1
Same with opalescent inner and outer globes	539	147	392	155	3.5	2.5
Alternating-current enclosed arc 110 volts, opalescent inner and clear outer globes	416	74	342	140	2.9	2.4
Same with opalescent inner and outer globes	416	74	342	114	3.6	3.0

for the open, because the light is much softer and steadier and the shadows are not so deep. As has already been pointed out, the enclosed arc is cheaper to look after on account of the long life of the carbons, and for this reason it is replacing the older style of lamps.

The preceding figures relating to arc lamps are here placed in the form of a table (Table I), for convenient reference.

28. The number of arc lamps required to illuminate a given space varies greatly and it is difficult to give any definite figures on this subject. Enclosed-arc lamps are now largely used for the interior illumination of mills and factories. The light from these lamps is steady and agreeable, and if they are provided with light opal globes or reflectors, a very even illumination may be obtained. In textile mills, the illumination must be very good; hence, more lamps are needed per unit of floor area than would be required, for example, in a foundry. Table II, based on values given by Uppenborn, will give a general idea as to the space that may be illuminated for each 450-watt lamp used.

TABLE II.

SPACE ILLUMINATED BY ARC LAMPS.

Space to be Illuminated.	Square Yards per 450-Watt Lamp.
Outdoor areas	2,000–2,500
Train sheds	1,400–1,600
Foundries (general illumination)	600–800
Machine shops	200–250
Thread and cloth mills	200–230

METHODS OF DISTRIBUTION.

29. We have considered the more important points relating to the arc itself, and it is now in order to consider the lamp proper. The arc lamp must, besides being arranged to hold the carbons in their proper position, be provided with a mechanism to start the arc, or "strike" the arc, as it is sometimes called, and also to feed the carbons together as they burn away. But before looking into the subject of arc-lamp mechanisms, it will be well to take up the methods used for supplying current to the lamps, because this has a bearing on the style of mechanism used.

SERIES DISTRIBUTION.

30. Most of the arc lamps used for street-lighting work are connected in series. For example, in Fig. 17, *A* represents an arc-light dynamo in the station and *l*, *l*, *l* are arc lamps situated at different points on the street;

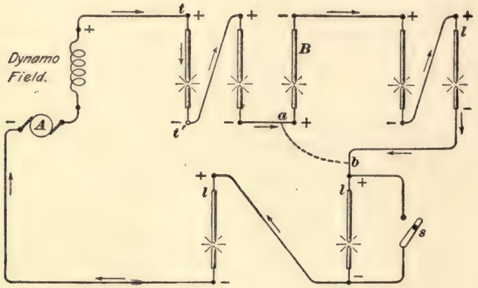


FIG. 17.

t, *t'* represent the terminals of the lamps, and are marked + and − to distinguish them from each other. The current flows through the lamps in the direction indicated by the arrows. The + terminal should in each case connect to

the upper carbon and the negative terminal to the lower carbon. If one of the lamps *B* should be connected in the circuit backwards, as shown, the current would enter at the lower carbon and the lamp would burn upside down; in such a case the terminals should be changed so that the current will enter at the top carbon, as in the other lamps. It is evident that in a simple series circuit the current through all the lamps must be the same unless there is leakage to ground and across to the other line, as indicated, for example, by the dotted path *a–b*. There will be no leakage to amount to anything if the line is in proper condition, so that it may be generally assumed that the current through each lamp is the same.

31. Since each lamp requires a certain current for its operation, it is evident that the current in the circuit must be kept constant, i. e., the number of amperes must be kept the same no matter how many lamps are in use. If we had 10 lamps in operation, each requiring 45 volts pressure, the dynamo would have to generate 450 volts. Suppose now that 3 of the lamps are cut out by short-circuiting them—lamps in a series circuit must always be cut out by short-circuiting, otherwise the circuit will be broken. In practice, each lamp is provided with a switch, as indicated at *s*, which is used to cut out the lamp by short-circuiting it and allowing the current to flow past it. If the voltage remains the same, it is evident that the current will increase, because we have decreased the resistance of the circuit; if the current is increased, the lamps will perform badly and perhaps burn out. In order to keep the current the same, the voltage should be reduced to 7×45, or 315 volts, when the lights are cut out. This is done by providing the dynamos with an automatic regulator. In case the lamps are operated in series by means of alternating current, a special transformer or regulator of some kind is frequently used to keep the current constant.

The series system of distribution is very widely used for street lighting, and is, in fact, about the only system that

can be used economically where the lights are scattered. As the same current flows through all the lamps, the system is operated by using a small current (usually from 6 to 10 amperes) at a high pressure. This calls for a small line wire (usually about No. 6 or No. 8 B. & S.), and thus requires but a comparatively small expenditure for copper.

32. Arrangement of Series Circuits.—If we take a simple series circuit, as shown in Fig. 17, the voltage generated by the dynamo will be the voltage per lamp multiplied by the number of lamps plus the voltage drop in the line. If the number of lamps operated is large, the voltage required becomes very high. Thus, in order to operate 75 lights, the machine must generate, roughly, 3,750 volts, allowing 50 volts per lamp, so as to include the drop in the line. Up to within a comparatively recent date, this was considered about as many lamps as could be operated from one machine, because of the difficulties of construction and operation for higher voltages. The result was that a station operating a large number of lights had to be equipped with a number of comparatively small machines, that were, at best, not very efficient. To overcome this, the so-called **multicircuit** machines were brought out, which are capable of operating 125 to 150 lights. The construction of arc dynamos has also been perfected to such an extent that machines are now built capable of operating 150 lights on a single circuit.

33. Multicircuit Series Machines.—Multicircuit machines are of two kinds, namely, those in which there are two or more circuits in series and those in which there are two or more circuits in parallel. The later styles of Brush machine are examples of the first kind. The new type of Western Electric machine is an example of the second. The simple, or older, type of Brush arc dynamo has already been explained. The newer and larger style is of the multipolar type, but is similar in principle to the old two-pole machine. The principal difference is in the arrangement of the circuit connections.

Suppose that A and B represent two of the commutators of a Brush machine. In the older machines they were connected in series, as shown in Fig. 18 (*a*), across a single circuit. The voltage between the terminals of the circuit *1–2* will therefore be equal to the sum of the voltages generated in the sections of the armature A and B. Suppose, however, that two series of lamps are arranged as shown in Fig. 18 (*b*). Here we have the same number of lamps connected in series as before, but they are divided into two circuits *1–2* and *3–4* and the pressure between points *1*, *2* is just one-half what it was before, because there are only one-half as many lamps connected between *1*, *2* that there were in the previous case.

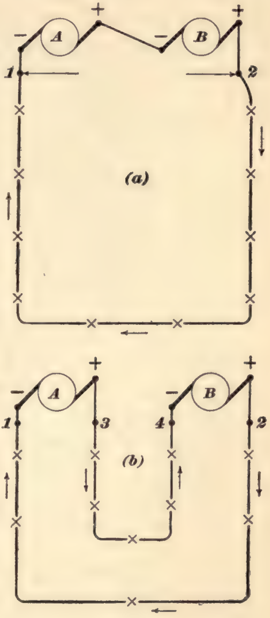


FIG. 18.

The whole object of this arrangement is to allow a large number of lamps to be operated in series, without introducing extremely high pressures on the line and dynamo. This may, perhaps, be more clearly understood by taking the example shown in Fig. 19. It would not be necessary to use a multicircuit arrangement for as small a number of lights as 10, but it will serve to illustrate the point. Allowing 50 volts per lamp, so as to include the line drop, we would require 500 volts for operating the single circuit in Fig. 18 (*a*). We can therefore represent the fall, or drop, in pressure from the + to the − terminal of the machine as indicated in Fig. 19 (*a*). Each section of the armature generates 250 volts, and as these

are connected directly in series, we have 500 volts across the circuit.

In the second case, we have the state of affairs shown in Fig. 19 (*b*). Suppose that we take the point *1* as a starting point and assume that it is at zero potential. The armature section *A* raises the pressure to 250 volts, so that there is a difference in pressure of 250 volts between points *3* and *1*. The current then passes through the circuit *3–4* containing

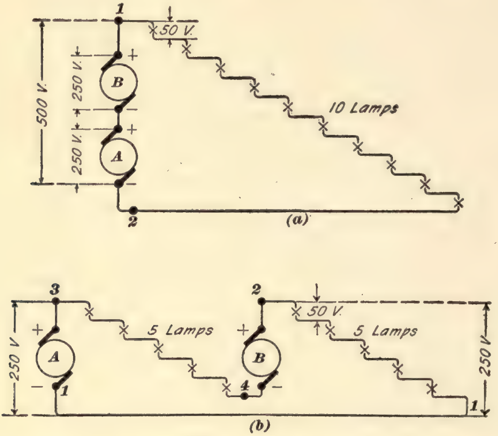


FIG. 19.

5 lamps, and the pressure drops off as indicated. Armature *B* again raises the pressure 250 volts, so as to operate the 5 lamps in circuit *2–1*.

It is thus seen that the multicircuit arrangement shown in Fig. 18 (*b*) operates the same number of lights as in Fig. 18 (*a*), and the maximum pressure between the terminals of the dynamo or between the terminals of either of the circuits is just one-half that in the single-circuit scheme of operation. If, however, the circuit is opened at any point in Fig. 18 (*b*), the pressure at the break will at once

rise to a pressure that is at least equal to the total pressure that the machine is capable of generating, and will be as high as the pressure given by the single-circuit arrangement. This is because at the instant that the circuit is opened there is but a very small drop through all the lamps. Moreover, the sudden decrease in the current causes a high induced E. M. F. in the windings of the machine on account of the sudden decrease in the lines of force threading the field and armature, and the pressure obtained at the break may, in many cases, considerably exceed the full-load voltage of the machine.

34. Since, in the multicircuit arrangement, as used on the Brush machines, the several circuits are in series with each other, the current must be the same in all and only one regulator is necessary on the dynamo. Where two independent circuits are operated in parallel from the same machine, it is evident that the voltage applied to each of the circuits must be capable of independent regulation. For this reason, the Western Electric multicircuit machines are provided with two independent regulators, one for each circuit. Some of the larger Brush machines are arranged so as to operate four circuits, though any of these dynamos may be operated as ordinary single-circuit machines if desired.

PARALLEL DISTRIBUTION.

35. When arc lamps were first introduced, parallel distribution was not very common, but now a large number of lamps are operated in parallel on constant-potential circuits, both direct and alternating. The increased use of enclosed-arc lamps for store and factory illumination is largely accountable for this. Such places were usually equipped with low-pressure constant-potential plants for incandescent lighting, and series-arc lamps for interior work are more or less objectionable on account of the high pressures necessary for their operation. The series-arc lamp is, however,

used for interior illumination in some large concerns where a large number of lights must be operated. Enclosed-arc lamps are operated in parallel by connecting them directly across the line, as indicated in Fig. 20. Each lamp is here provided with a double-pole switch and cut-out or branch block carrying fuses for protection in case a short circuit occurs in the lamp. Most lamps have a switch mounted on them, and it is only necessary to provide a separate switch, as

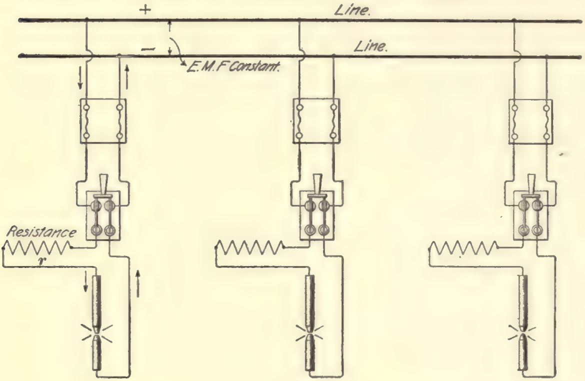


FIG. 20.

shown, when it is wished to control the lamp from a distant point. Of course, the switch is arranged to open the circuit through the lamp, and not short-circuit it, as when cutting out a series lamp.

Fig. 21 shows the lamps connected to an ordinary 110-volt direct-current system. By using lamps with a slightly different mechanism, they may be operated from the secondary of a transformer, as shown in Fig. 22. When arc lamps are operated from constant-potential direct-current mains, it is necessary to connect a resistance *r*, Fig. 20, in series with the arc. This is necessary for two reasons. In the first place, the lamps will not regulate well without it, and in the second place, the voltages used on constant-potential

circuits are usually considerably higher than the voltage required by a single arc lamp, so that the excess voltage must be taken up in a resistance.

If an arc lamp were connected directly to constant-potential mains, without the intervention of any resistance, its action would be unstable. If the current flowing through an arc increases, the resistance of the arc decreases, because the increased current causes the cross-section of the arc to

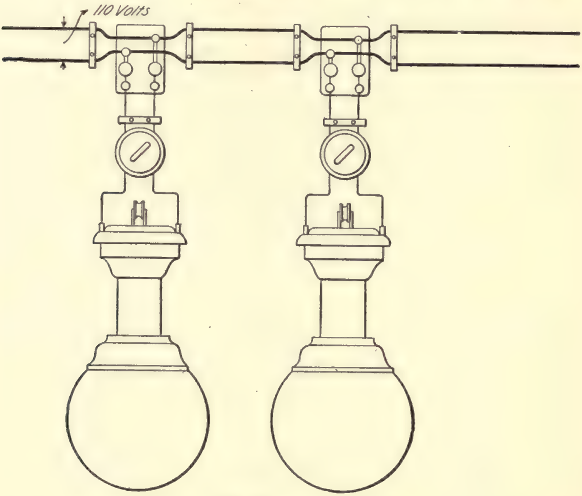


FIG. 21.

increase. On the other hand, if the current decreases, the resistance of the arc increases. The consequence is that if the constant voltage of the mains was just equal to that required by the arc and if the current through the arc should, for any reason, decrease a little, the resistance offered by the arc would at once increase, thus causing a further decrease of current and increase of resistance, with the result that the arc would go out. On the other hand, an increase of current would result in a decrease of resistance,

and this would cause a still further increase of current. The operation of the lamp would therefore be unstable, and would fail to maintain a constant arc for any length of time.

Now, if a line voltage somewhat higher than that required by the lamp is used and sufficient resistance inserted to give

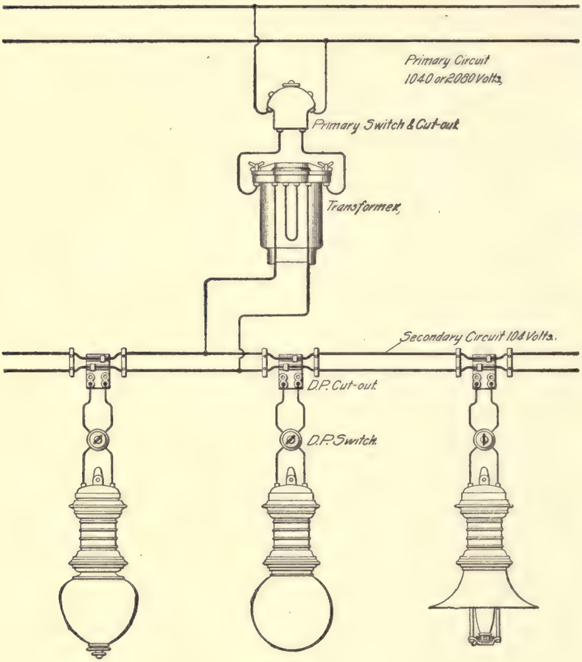


FIG. 22.

a drop through the resistance sufficient to bring the arc voltage to the correct amount when the normal current is flowing, the lamp will become stable in its action. For, suppose the current decreases a little; the drop through

the resistance will decrease and, since the line voltage is constant, the voltage across the arc will be increased, thus compensating for the increased arc resistance. Also, if the current increases, the drop through the resistance at once increases and the voltage across the arc is lowered. In alternating-current lamps a *reactance* or *choke coil* takes the place of the resistance. This consists of a coil of wire wound on an iron core. When the alternating current passes through the coil, the changing magnetism set up generates a counter E. M. F. in the coil. The choke coil wastes less energy than the resistance, but, of course, it cannot be used with a direct-current lamp, as the direct current is not capable of setting up the alternating magnetism necessary to generate the counter E. M. F. The resistance or choke coil, as the case may be, is generally mounted in the top of the lamp and is arranged so that it will be ventilated, in order to insure cool running. Resistance coils in arc lamps are usually made of German silver and are in most cases wound on porcelain fittings.

36. Lamps in Multiple Series.—The use of the enclosed-arc lamp allows single lamps to be operated in parallel on 100- to 120-volt circuits without excessive waste. This is because these lamps take such a high voltage at the arc (from 70 to 80 volts). Open-arc lamps take only from 40 to 50 volts at the arc; hence, if these lamps were operated singly across 100- to 120-volt circuits, there would have to be from 60 to 80 volts taken up in the resistance. To avoid this, open-arc lamps were usually operated two in series, as shown in Fig. 23, thus requiring about 90 volts for the arc, and leaving only about 20 volts to be taken up in the resistance R. Quite a number of lamps were at one time operated in this

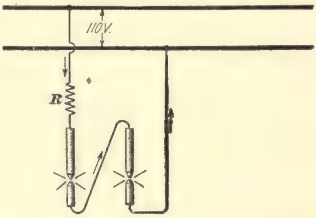


FIG. 23.

way, but the arrangement never worked entirely satisfactory. If one lamp failed to work properly, it affected the other, and the service was not as good as it should have been. This method of operating lamps has therefore been replaced by the use of the single enclosed-arc lamp connected directly across the mains.

The two methods of distribution to which we will confine our attention will be the series system, used almost exclusively for street lighting, and the simple parallel system, used principally for interior arc lighting.

ARC LAMPS.

37. The different makes and types of arc lamps in commercial use are so numerous that it is impossible to give a complete list of them here. This is, however, not necessary, because many of the types differ only in mechanical details and involve no new principles. Complete instructions concerning the different makes are furnished by the manufacturers, and all that is necessary is to point out the features peculiar to lamps adapted to the various kinds of service.

38. No matter what type of lamp is used, it must be arranged so that the carbons may be kept apart at the proper distance. In a few special cases, as, for example, in some searchlights or projection lamps, this is accomplished by hand. In all commercial lighting work the lamp must be provided with a mechanism that will feed the carbons together as they are consumed. In most cases, the lower carbon is fixed and the top one is fed down in such a way as to keep the arc of the proper length. When the upper carbon is released by the lamp mechanism, it is fed down by the attraction of gravity. Gravity is therefore the propelling power in most lamps, and the whole lamp mechanism is essentially a device first to separate the carbons and start the arc and then to release the carbon and allow it to feed down at the proper time. This feeding must be

accomplished without disturbing other lamps on the same circuit. The mechanism generally consists of a clutch or clockwork controlled by electromagnets, the current in which depends on the condition of the arc and which releases the clutch or clockwork, thus allowing the carbon to feed down whenever the arc exceeds the length for which the mechanism is set.

As stated before, the mechanism must also be arranged so that the lamp will regulate without affecting other lamps on the circuit. This is comparatively easy to accomplish in the case of lamps operated in parallel, because the pressure across the mains is constant, and each lamp is independent of its neighbor. In the case of the series lamp, however, the current that flows through one lamp also flows through all the others, and each lamp must be arranged so as to feed when necessary, no matter what may be the condition of the others.

CONSTANT-POTENTIAL LAMPS.

39. The regulation of constant-potential lamps is usually brought about by an electromagnet or solenoid that is connected directly in series with the arc. This solenoid operates either a clutch or clockwork so as to feed the carbon when required. For example, take the simple arrangement shown in Fig. 24. This is not intended to illustrate any particular make of lamp, but simply to bring out some of the points connected with the operation of constant-potential lamps in general. By far the greater number of lamps in use employ a clutch rather than a clockwork feed. In Fig. 24, t, t' are the lamp terminals connected across a constant-potential circuit; r is the resistance inserted to take up the surplus voltage and to make the action of the lamp stable; S is a solenoid connected directly in series with r and arranged to suck up the core c when current passes; d is the clutch, which we have here shown simply as a washer with a hole a little larger than the rod e, to which the upper carbon is attached; f is a stop against which d strikes when

the core *c* lowers a sufficient amount; *g* is the top (positive) carbon and *h* the lower (negative). The current enters at *t*, passes through *r* and *S* to the brush *k*, which makes a sliding contact with the carbon rod *e*. From *e* it passes to the top carbon *g*, thence to the lower *h*, and out at *t'*. The path is as indicated by the arrows. This is supposed to be a direct-current lamp; hence, the current should flow, as shown, so as to bring the crater in the upper carbon. With an alternating-current lamp, it would, of course, make no difference how the lamp was connected.

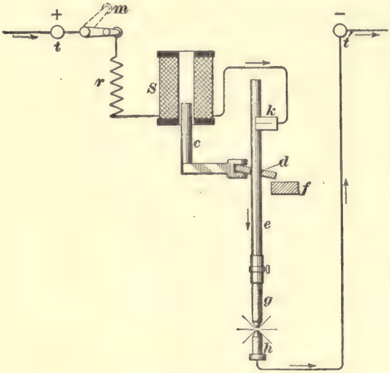


FIG. 24.

40. When the current is off, *d* comes down against *f* and is tilted so that *e* slides through until *g* strikes *h*. As soon as the current is turned on by closing switch *m*, the core *c* is at once sucked up to the full limit for which the lamp is adjusted. As soon as *c* moves up *d* tilts, as shown in the figure, and grips *e*, thus raising *g* and striking or starting the arc. As the carbons burn, the arc gradually becomes longer and, consequently, the resistance of the lamp, as a whole, increases. One fact that must not be lost sight of is that this lamp is connected in multiple across a constant-potential circuit; hence, as the arc lengthens, the current through the lamp is bound to decrease, no matter what current the other lamps on the same circuit may be taking. The result is that as the arc gets longer, *S* becomes weaker because of the smaller current and *c* lowers a little. When *c*

has moved a short distance, *d* comes in contact with *f*, and as *c* drops still farther, *d* is tipped a little and allows rod *e* to slide through. As soon as the carbons come nearer together, the current at once increases, *c* is pulled up, and the rod is held until the current becomes small enough to allow it to feed again. In this way the carbon is fed down, a little at a time, and the feeding is brought about by the decrease of the current due to the increase in the length of the arc. It is thus seen that the regulation of a constant-potential lamp may be brought about by the use of a simple series solenoid, or magnet, and as a matter of fact the mechanism of these lamps is very simple; some of the modern enclosed-arc lamps have but little more mechanism than that indicated in Fig. 24.

SERIES-ARC LAMPS—OPEN ARC.

41. When we come to consider the regulation of series-arc lamps and the mechanism necessary for their operation, we have a different problem to deal with. In the first place, when lamps are run in series, the current is always maintained at a constant value, or it should be if the regulator on the dynamo works properly. It is evident, then, that a series magnet alone is not able to do the regulating, because its pull remains the same no matter what might be the condition of the arc. Again, there must be some device in the series lamp that will preserve the continuity of the circuit in case a carbon should become broken, fall out, or the circuit through the lamps become broken in any way. If such a device is not provided, an open circuit in the lamp will result in all the lights on the circuit going out. This device is called a **cut-out.**

42. Although the current through the arc remains constant in a series system, the voltage across the arc increases as its length increases, and this increased voltage is made to bring about the regulation. Suppose that we modify the

simple lamp shown in Fig. 24 by extending the core c downwards and adding another solenoid S', as shown in Fig. 25. We can also omit the starting resistance r, as this is to be a series lamp, and there will be no excess voltage to be taken up; the current is maintained at a constant value and resistance is not necessary to insure stability of operation. This second coil S' is to be wound with a large number of turns of fine wire, so that when it is connected in shunt across the arc, as shown, but a small current will flow through it. The coils S, S' pull c in opposite directions, and c will always take up such a position that the two pulls are balanced. The action of the lamp is, then, as follows:

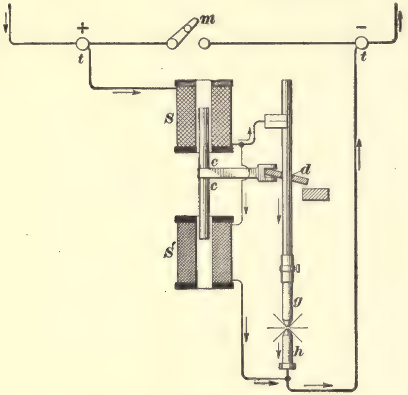


FIG. 25.

When the lamp is out, the carbons g, h are in contact. Notice that the switch m in this lamp is connected across the terminals, and in order to put out the lamp, m is closed. This is just the reverse of the constant-potential lamp that is operated in parallel. When the lamp is thrown into circuit, the main current passes between g and h, but since the carbons are in contact there will be little or no drop in potential between them and, hence, practically no current will pass through the shunt coil S'. The result is that coil S

pulls up the plunger, and in so doing lifts the upper carbon and starts the arc. The instant, however, that the carbons g, h separate, current flows through S', because there is then considerable difference of potential between g and h. The result is that as the carbons are separated, the downward pull of S' becomes stronger until it finally balances the upward pull of S, when the arc remains stationary. As the carbons burn away, the arc becomes longer; hence, its resistance increases and the voltage across the arc increases. The pull of S does not change, because the main current is maintained constant by the dynamo. The pull of S' keeps increasing as the carbons burn away, and c is gradually pulled down until the lamp feeds. As soon as g feeds down the pull of S' decreases, because the arc shortens; hence, the position of c becomes again balanced, and so on, the plunger c moving back and forth through a small range between the coils. By properly adjusting the clutch, such a lamp may be made to keep the arc at the proper length within very close limits.

43. The student should carefully note the essential features of the above lamp, because practically all series lamps depend for their operation on the use of two coils. One of these, the series coil, carries the main current, and is opposed by the shunt coil, which carries a current depending on the length of the arc. The current in the shunt coil depends only on the length of the arc in each individual lamp and is independent of the condition of the other lamps. A lamp of this kind is known as a **differential lamp,** because the position of the core c depends on the difference in the pulls between S and S'. The simple series lamp shown in Fig. 25 is not provided with a cut-out, but the action of this device will be explained later when some of the different types of lamp are described. In some makes of lamps the coarse-wire and fine-wire coils are both wound on the same spools, and instead of using solenoids with a core that is drawn into them, the coils are provided with a fixed iron core and arranged so as to attract an

armature that releases the clutch or clockwork mechanism, as the case may be. The Thomson-Houston (T. H.) and Brush lamps use two coils wound on the same core, and the armature operates a clutch. In the Wood lamp, solenoids are used very much as indicated in Fig. 25, and these lamps are made for either a clockwork feed or a clutch feed. In lamps having a clockwork feed, the rod that holds the upper carbon is usually provided with a rack cut along one side. This rack engages with a gear-wheel that is held from turning by means of a ratchet wheel and pawl. The frame on which these gears are mounted is pivoted, and its movement is brought about by the controlling magnets or solenoids. When the frame is moved by the action of the shunt magnet, the pawl is thrown out of interference with the ratchet wheel and the lamp feeds. The movement at any one feeding is very slight, and the carbons approach each other so gradually, if the lamp is properly adjusted, that a steady light is the result. The feeding mechanism of a clockwork lamp is slightly more complicated than that of a clutch lamp. In the latter, the carbon rod must be kept clean and bright, or else the clutch will not act properly. If, however, a clutch lamp is looked after as it should be, it will feed smoothly and give good results. The use of clockwork mechanisms is not as common as it once was, and practically all the modern lamps are operated by a clutch of some kind.

EXAMPLES OF ARC LAMPS.

CONSTANT-CURRENT SERIES LAMPS—OPEN ARC.

44. The constant-current series arc lamp using direct current and burning with an open arc has in the past been the style of lamp almost universally used for street lighting. There are thousands of these lamps in use, and notwithstanding the fact that the regulating mechanism of some of them is more or less complicated, they have given very

good service and their general design has been changed but little. It is now customary to run more lamps on a circuit than was once the case; hence, the voltage of the circuits is higher, and it is necessary to provide the lamp mechanism with better insulation than was used in the older lamps. The design of the clutch has also been modified from time to time, but as a whole the mechanism of these lamps remains about the same in principle as it was when they were first introduced. The open arc is being gradually ousted for street lighting by the enclosed arc, but as there are still very large numbers of the former in use, it will be necessary to explain a few of the more important types. For this purpose we will select the Brush, the T. H. (Thomson-Houston), and the Wood lamps, as these have been more largely used than any others.

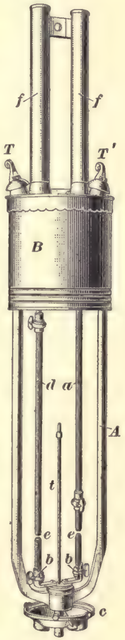


FIG. 26.

45. When an open-arc lamp is required to burn all night, it is necessary to provide it with two carbons, arranged so that when one is consumed the other will start up. Fig. 26 shows a Brush double-arc lamp for all-night burning. This view shows the lamp with the globe removed and with one pair of carbons nearly consumed. As soon as the carbon rod *a* gets to its lowest point, the rod *d* starts feeding, and the other pair of carbons are consumed. In order to obtain a long life for the carbons, some companies use single lamps, but instead of the ordinary $\frac{7}{16}$-inch or $\frac{1}{2}$-inch round carbons, they use $\frac{5}{8}$-inch or even larger. This results in a long life, but the large carbons are apt to cast objectionable shadows. Another scheme for securing long life for the carbons of open arcs is to use flat carbon plates, but this, also, has the bad feature of giving poor light distribution.

46. The Brush Arc Lamp.—The general appearance of this lamp is shown in Fig. 26, which will serve to illustrate

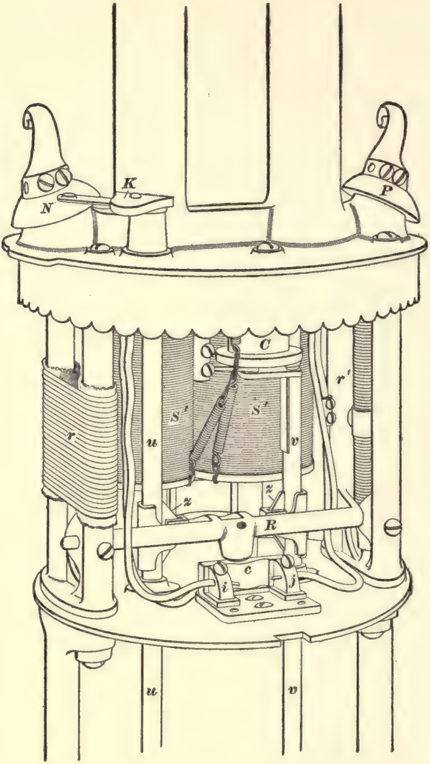


FIG. 27.

the appearance of all the lamps of this class. *A* is the frame carrying the lower carbon holders *b*, *b* and the globe

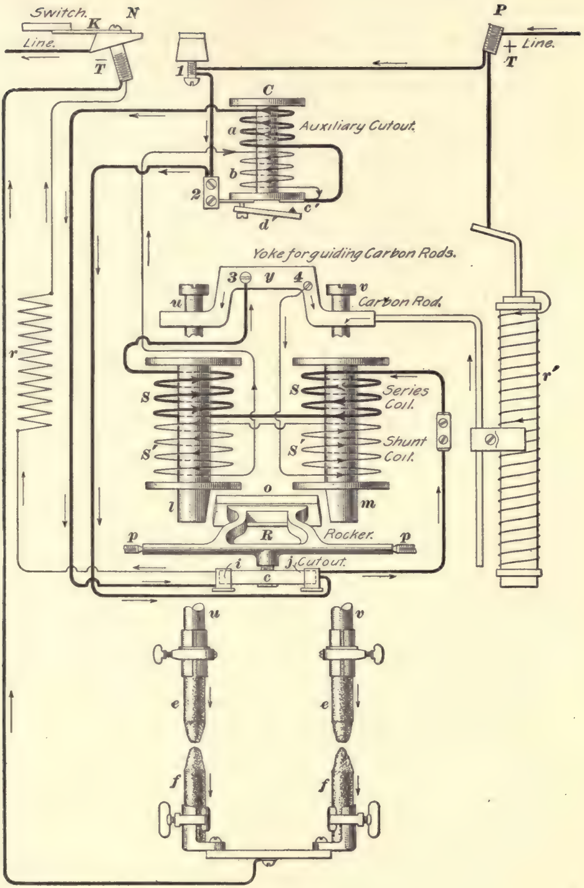

Switch.
K
N
Line.
T
P
+ Line.
T
1
C
Auxiliary Cutout.
a
b
2
c'
d'
Yoke for guiding Carbon Rods.
3
y
4
u
v
Carbon Rod.
r
r'
S
S
Series Coil.
S'
S'
Shunt Coil.
o
l
m
R
Rocker.
p
p
i
j Cutout.
c
u
v
e
e
f
f

FIG. 28.

holder c; B is the cover for protecting the lamp mechanism; a is one of the carbon rods carrying the upper carbon holder. When the lamp is newly trimmed, these rods push through the case and are protected by the chimneys f, f. T, T' are the lamp terminals

Fig. 27 shows the relation of the parts of the lamp and Fig. 28 the connections. The coils S, S' and a, b are really wound on top of each other, but we have here shown them side by side for the sake of clearness. P and N are the positive and negative terminals of the lamp. The poles of the regulating magnet are at l, m; and o is the armature that moves up and down with the rocker R hinged at the points p, p. The clutches are not shown in Fig. 28, but they can be seen at z, z, Fig. 27. Their operation will be described later. The two upper positive carbons e, e are attached to the carbon rods u, v. When no current is flowing through the lamp, the armature o, Fig. 28, and the rocker R are in the lowest position, and the strip c comes in contact with the terminals i, j, thus cutting out the lamp and allowing the current to take the path P–1–2–j–i–r–N. C is an auxiliary cut-out that is intended to cut out the lamp whenever the pressure across the arc exceeds 70 volts. It consists of a magnet provided with two windings a and b, connected as shown, and a pivoted armature d' that makes contact at c' when the magnet acts. A small amount of adjustable resistance r' is in shunt with the series magnet S. By regulating this resistance, the pull of the series magnet may be adjusted; r is another small resistance connected in series with the cut-out c.

47. The action of the lamp will be understood by referring to Fig. 28. First we will suppose that the lamp is connected in circuit but is short-circuited by the switch blade K on top of the lamp being on contact *1*. The current then flows directly across from P to *1*, thence through K and out on the line. Under these circumstances no current flows through the mechanism, the armature will be down, the carbons in contact, and piece c will connect i and j. Now, suppose

switch K to be opened. The current will then take two paths as follows: P–r'–y–u–e–f–N and P–1–2–j–i–r–N. However, since S, S are connected in shunt with r', a portion of the current will flow through the series coils, taking the path 1–2–j–S–S–y, and the armature will be lifted, thus separating the carbons and establishing the arc. As soon as the armature is raised, the contact c leaves the terminals i, j, and the current passing through r is interrupted with the exception of the small current that passes through the fine-wire coils S', S'. The clutch has now lifted the carbons and the lamp is in operation. One end of the fine-wire coil connects to the upper carbon, as indicated at 4, and the shunt current takes the path 4–S'–S'–b–c'–a–i–r–N. It is thus seen that the coils S', S', and b are in series and are connected in shunt with the arc. Coils a and b tend to raise the armature d', but the current flowing under normal conditions is not sufficient to actually raise it. It should be noticed that the current circulates around S', S' in a direction opposite to that in S, S.

48. As the carbons burn away and the arc becomes longer, the current through the shunt coils increases, thus making the poles of the controlling magnet weaker and allowing the armature and rocker to gradually drop down. This lowering continues until the clutch releases and allows the carbon rod to slide down a little.

Fig. 29 shows a form of clutch used in this lamp. The piece a rises and falls with the rocker, and when it is raised the piece b is clamped against the carbon rod by means of the small lever d, and the movement of the armature lifts the whole rod. When a descends, because of the magnets becoming weaker, the whole clutch and rod move down until the piece e strikes the plate f. The piece g then remains stationary, while a moves down a little farther, thus moving the small lever d and unlocking the clutch.

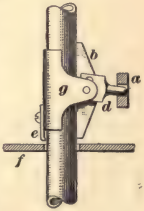


FIG. 29.

49. Suppose now that a carbon rod should stick in some way and fail to feed properly. The arc would gradually become longer and the voltage across it would increase until the current in the shunt circuit became much larger than the normal amount; this would cause the armature d' of the auxiliary cut-out C to be drawn up and contact made at c'. The current would then take the path P–1–2–d'–c'–a–i–r–N; the series and shunt coils would both be cut out, but the current flowing through a would hold up d'. The cutting out of the main coils would cause the rocker to drop and c would then come into contact with i and j, thus cutting out the auxiliary cut-out. If the dropping of the rocker frame should make the carbons come together, part of the current will pass through the series coils by the path 2–j–S–S–3–u–e–f–N, because in the other path we have the resistance r. The result is that the lamp will start up again. If the resistance r were not used, the path 2–d'–c'–a–i–N would be of low resistance compared with 2–j–S–S–3–u–e–f–N, and the lamp would not relight; hence, the use of the resistance r. If a carbon should become broken or fall out, all the current would for an instant pass through the fine-wire coils; hence, d' would at once rise and cut out the lamp. Of course, in this case c would come into contact with i and j and remain there, because the carbons could not come into contact again and allow the lamp to relight. If no cut-out were provided, there would not only be danger of a break in the circuit, due to the carbons being broken or failing to feed, but in addition the shunt coils would be burned out because the whole current would, under these circumstances, pass through them.

50. From the above description, it will be seen that this lamp works on the differential principle. When the lamp is not in operation, the carbons are together. As soon as the current passes, the series coils separate the carbons, thus starting the arc. The regulation is then brought about by the opposing action of the shunt coil causing the release of the clutch.

THE THOMSON-HOUSTON (T. H.) LAMP.

51. The Thomson-Houston open-arc series lamp is one that has been very largely used for street lighting on constant-current circuits. Notwithstanding the fact that the mechanism of this lamp is somewhat complicated and contains a large number of parts, it has given, on the whole, very good service; in fact, it may be said of most of the common types of constant-current lamps that although the conditions under which they must work are trying, they have given good service. The T. H. lamp has been changed comparatively little, as regards its main features, since it was first brought out. Some of the smaller details, such as the clutch, cut-out contacts, etc., have been changed, but the general arrangement has remained much the same. In the later lamps the insulation of the frame has been improved, owing to the fact that more lamps are now run on a circuit than formerly and the pressure applied to the circuits is correspondingly higher.

52. The T. H. lamp differs considerably from the differential lamp just described. The series coil is used only to start the arc, and when the lamp is in operation under normal conditions, no current flows through it. The regulation is effected by means of the shunt coil alone, and when the lamp is not burning the carbons are separated instead of being together, as is the case with most lamps. Fig. 30 (*a*) and (*b*) shows the mechanism of the T. H. double lamp, but for the present we will confine our attention to Fig. 31, which shows the connections and the general arrangement of the essential parts. This figure is intended to show only the principle of operation and is not supposed to be an exact illustration of the parts of the lamp itself, as some of the minor parts have been omitted in order to make the diagram as simple as possible. A and B are the + and − terminals in the shape of hooks, so that the suspending wires may also be used to conduct the current into the lamp; E E is the carbon rod carrying the upper carbon m; the lower carbon n is supported by the lamp frame, not

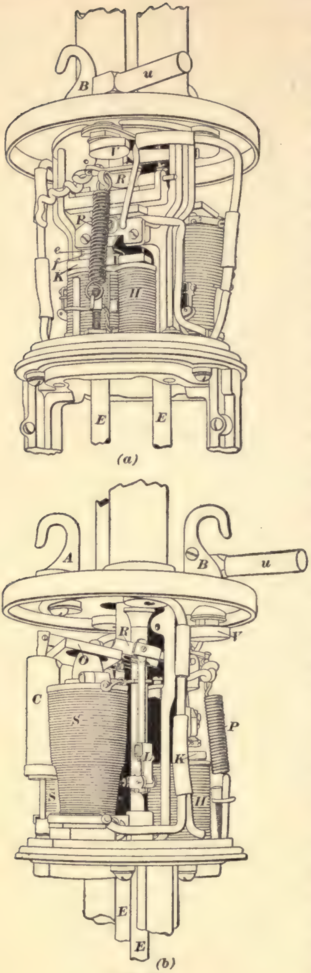


FIG. 30.

shown in the figure; R is a rocker frame pivoted at x and carrying an iron armature O. This latter has two holes in it, through which the conical pole pieces of the magnet project when the armature is pulled down. When the lamp is not in operation, this frame is held at its highest position by the adjustable spring P; the movements of the rocker are steadied by the dashpot C; s is the series coil wound over the shunt coil M; there are two spools side by side, as shown in Fig. 30; H is a small coil in series with the carbons. H is called the starting coil, and its office is to cut the series coil s into or out of action. It is provided with a movable armature K, on which is mounted the insulated contact f tipped with silver; e is another silver-tipped contact connected to the point c. When no current flows through H, e and f are in contact; p and r are the cut-out contacts, the action of which will be described later. L is the clutch and its action is very similar to the one just described for the Brush lamp.

53. We will first consider the operation of the lamp under ordinary conditions. In Fig. 31 it will be noticed that the clutch L and frame R are up and that the carbons are drawn a short distance apart. In order that

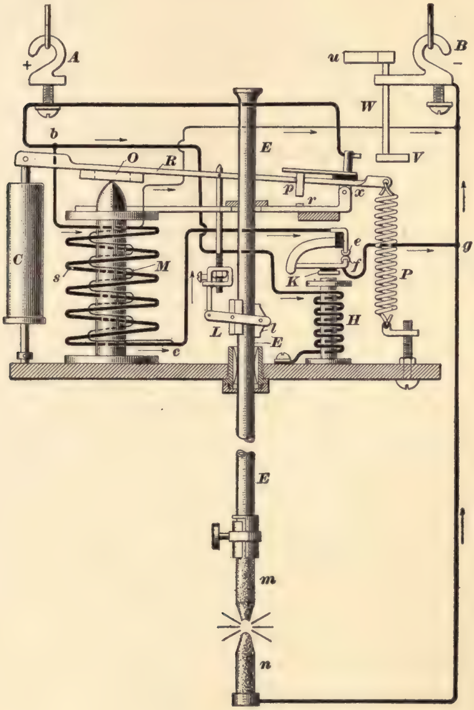


FIG. 31.

the lamp may be started, m must be lowered so as to touch n, and this is accomplished as follows: At the instant that the current is turned on, e and f are in contact, because no current is flowing through H; hence as soon as

the current passes, it takes the path *A–b* through the series coil *s* to *c–e–f–g–B*. Practically no current would go from *c* through the shunt coil to *B* because of the high resistance of this path compared with the other. As soon as the current passes through *s*, the rocker is pulled down and the clutch is released, bringing the carbons in contact and allowing part of the current to take the path *A–b–H–E–m–n–B*. As soon as current passes through *H*, the armature *K* is attracted, thus separating *e* and *f* and cutting off the current through the series coil *s* with the exception of the small current through the shunt coil *M*. The result is that the rocker rises and carries with it the upper carbon, thus separating the carbons and starting the arc. As soon, however, as the carbons are separated, there is considerable difference of potential across the arc; hence, the shunt coil *M* takes its normal current and holds the rocker at the proper point to give the length of arc for which the lamp is adjusted. It is thus seen that the series coil is cut out after the arc has been started.

54. The lamp is now supposed to be burning, and as the arc grows longer the pull of the shunt coil increases and the rocker is gradually pulled down until the shoe *l* of the clutch comes against the stop, and any further movement causes the rod *E* to slide down a little. The pull due to the shunt coil decreases with the shortened arc, and the rocker rises to its normal position. The feeding is thus brought about by the action of the shunt magnet working against the spring *P*.

55. If the carbons should stick and fail to feed, the arc will gradually grow longer until the pull exerted by the shunt magnet will be sufficient to bring the cut-out contact *p* down against *r*. The current will then take the path *A–p–r–E–m–n–g–B* in preference to passing through *H*. *K* will then rise and bring *e* and *f* in contact. The current will then take the path *A–b–s–c–e–f–g–B*; the series coil will hold down the armature and the lamp will be cut out unless the movement of the rocker should release

the rod and allow the carbon to feed, in which case the lamp will continue to burn and rocker *R* will rise again, thus separating *p* and *r*.

56. If a carbon should fall out, the current through the shunt will suddenly increase and the current through *H* will be interrupted, *R* will be pulled down, and *K* will rise the final result being that the lamp is cut out.

57. When the lamp is to be switched out, the switch *W* is used. This switch takes the form of a cam *V* operated by the lever *u*, seen at the top of the lamp, Fig. 30. When the handle is turned to one side, the cam comes against the casting that carries the upper cut-out contact, and thus establishes a short circuit from terminal to terminal. Fig. 30 shows the general arrangement of the mechanism of this lamp. The lettering of the parts corresponds to that given in Fig. 31, so that they may be readily identified.

THE WOOD ARC LAMP.

58. This lamp operates on the differential principle and has been made both for clockwork and clutch feed. In the clockwork lamp the carbon feeds down whenever the movement of the rocker throws the pawl out, so as to allow the clockwork to operate. In the clutch lamp the movement of the rocker controls the clutch in much the same way as for the lamps already described.

Fig. 32 shows the general scheme of connections for a Wood lamp. Here the series coils *M* are arranged vertically above the shunt coils *S*. There are two series and two shunt coils. Two plungers connected by a crosspiece *g* are moved up and down by the coils, or solenoids, as described in Art. **42.** This armature moves a pivoted frame, not shown in the sketch, and thus brings about the regulation.

59. When the lamp is not in operation, the carbons are together and the plungers are at their lowest position.

When this is the case, pin *d* rests on spring *e*, which is in electrical connection with the framework and the carbon rod *h*. When the current is turned on, it takes the paths *A–p–d–e–R–B* and *A–p–k–l–M–M–m–n–B*. The resistance *R* is in itself small, but it is fairly large compared with that of the series coils *M*, and enough current will take the path through the series coils to lift the plungers and start the arc by separating the carbons. At the same time, contact is broken between *d* and *e*, so that all the main current passes through the series coils. The shunt coils *S* are connected across the arc, and as soon as the arc is started, they set up a pull in opposition to the series coils. When the arc has burned to a certain length, the plungers are pulled down enough to allow the carbon to feed. The action of the lamp, as a whole, is almost identical with that of the elementary lamp described in Art. **42.**

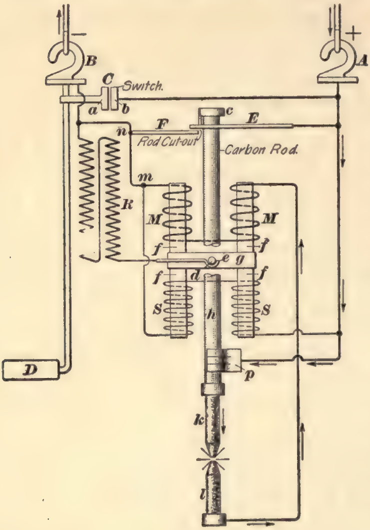


FIG. 32.

60. If the rod should stick, the arc gradually grows longer until the pull of coils *S* brings *d* down against *e* and thus cuts out the lamp. The object of using the resistance *R* is to enable the lamp to start up. If *R* were not present, the resistance of the path *p–h–d–e–B* would be so low compared with the path *p–h–k–l–M–M–m–n–B* that not enough

current would flow through the series coils to start the lamp. This lamp is also provided with a rod cut-out, as shown at *E*, *F*. This short-circuits the lamp when the carbons have become nearly consumed. *C* is a hand switch operated by turning the handle *D*; it is used to cut the lamp out of the circuit whenever desired. When the handle *D* is turned, *a* and *b* are brought into contact, thus making a direct connection between *A* and *B*.

61. The above descriptions of three of the leading styles of constant-current series lamps will give the student an idea as to the main features of such lamps. It should be noticed that in all of them the arc is started by means of a series coil and that the feeding is regulated by means of a shunt coil. Most of the series lamps take about 9.6 amperes for the 2,000 candlepower size and 6.6 amperes for the 1,200 candlepower size. The voltage across the arc is from 40 to 50 volts and the carbons are generally $\frac{7}{16}$ inch, $\frac{1}{2}$ inch, $\frac{9}{16}$ inch, or $\frac{5}{8}$ inch in diameter.

CONSTANT-CURRENT SERIES LAMPS—ENCLOSED ARC.

62. Comparison Between Open and Enclosed Arcs. Up to within a comparatively recent date, the open-arc series lamp had the field of street lighting practically to itself. The constant-current enclosed-arc lamp is, however, now being extensively installed. It is used nearly altogether for new work, and is replacing the older open-arc lamp in many places. The reason for this is not that the old lamps were unsatisfactory in operation, because they have been operated for years and, taking everything into consideration, have given admirable service. Neither does the enclosed arc give more light than the open lamp; in fact, it does not give quite as much for the same amount of power consumed. Even assuming that the arcs themselves give as much light, the use of the two globes in the case of the enclosed arc cuts down the amount of light more than does the single

globe that is used with the open arc. This, however, is counterbalanced by the more agreeable character of the light given by the enclosed arc. The strong contrasts so noticeable with the open arc are softened down, and the change from open to enclosed arcs is one that is generally popular, even if the intensity of illumination is somewhat reduced. The true reason of the change is, however, that the enclosed arcs are cheaper to operate.

63. Voltage Required by Series Enclosed-Arc Lamps. As stated previously, the enclosed arc is much longer than the open arc. This is necessary because the carbons do not become pointed, there is no well-defined crater, and the carbons must be separated considerably to allow a proper distribution of light. Also, a short enclosed arc will not work well, owing to the deposition of carbon on the carbon points. These lamps, therefore, take a rather small current, and the voltage across the arc is high. This is a decided advantage where lamps are operated in parallel on constant-potential systems, where the pressure is nearly always higher than that actually required by the lamp and the excess voltage has to be taken up by a resistance or choke coil. When, however, it comes to operating lamps in series, the high voltage across the arc becomes, to a certain extent, a disadvantage. It means that for a given number of lamps operated on a circuit, the pressure at the terminals of the circuit must be higher in case enclosed arcs are used. This makes it difficult to operate a large number of lamps from one machine, but by using the multicircuit arrangement, the pressure applied to each circuit may be kept down. Constant-current arc machines are now built to generate as high as 11,000 volts, which is about equivalent to 150 enclosed arcs. It is quite common to find as many as 100 lamps operated on a single circuit. It must be remembered, however, that where these high voltages are used, the line insulation must be thoroughly good, and attempts to use these pressures upon old lines having poor insulation have resulted in continual trouble, to say nothing of the danger involved.

64. Alternating-Current Series Enclosed-Arc Lamps. Enclosed arcs are now very often operated in series by constant current on alternating-current systems, i. e., the alternating current through the series of lamps is maintained at a constant value. The lamps used do not differ essentially from those for constant direct-current circuits, except that all magnet cores and armatures are laminated to prevent heating due to eddy currents, and the mechanism is designed so as to avoid disagreeable humming. The methods for supplying current to series alternating-current lamps and the arrangements for maintaining the current at constant value will be taken up when the subject of station apparatus is considered.

65. Current.—Series enclosed-arc lamps are ordinarily operated at about 6.6 amperes, and the voltage per lamp is from 70 to 78 volts, depending on the length of arc for which the lamp is adjusted. These lamps have also been built for a current as large as 8 amperes, with a correspondingly lower voltage, but the values given above are the ones commonly met with.

66. Remarks on Enclosed-Arc Lamp Construction. The mechanism of an enclosed-arc lamp generally contains the same essential features as the corresponding open arc, but in most cases the arrangement is simpler. The open arc must be fed frequently, because the carbons burn at a comparatively rapid rate and the clutch or other feeding mechanism must be accurately adjusted and kept in good condition if the lamp is to burn steadily. For this reason, the upper carbon of an open-arc lamp is attached to a carbon rod on which the clutch operates, and which is, or should be, kept in a clean, polished condition. The current is generally carried to the top carbon by means of a copper brush pressing against the rod. In the enclosed-arc lamp the operation of feeding takes place at comparatively long intervals, and the feeding mechanism does not need to be so delicately adjusted. It is, therefore, a common practice to

have the clutch operate directly on the carbon and to dispense entirely with the carbon rod. Such lamps are spoken of as having a **carbon feed.**

The doing away with the carbon rod makes the construction simpler and cheaper, besides allowing the lamp to be made shorter than is usual where a carbon rod is used. Short lamps are desirable for inside work, as they look better, especially in places where headroom is limited. Some enclosed-arc lamps, however—the Wood lamp, for example—use the carbon rod. The omission of the carbon rod, while it simplifies the construction in some respects, is not without its drawbacks. It is not as easy to conduct the current into the carbon without interfering with its free movement, and the contact rings or other devices on many of these lamps give trouble. To get around this, some makers use a flexible cable or chain attached directly to the carbon holder; but flexible cables are also apt to give trouble unless they are looked after and kept in good condition.

On account of the long arc common to enclosed-arc lamps, their mechanism must be arranged so that it will have a long pick-up; i. e., when the lamp starts up the mechanism must be such as to pull the carbons a considerable distance apart. In the case of series lamps, an automatic cut-out must, of course, be provided.

67. In taking up the subject of enclosed-arc lamps, we will confine our attention to two or three typical examples that will serve to bring out the essential points relating to their construction and operation. The number of different makes of enclosed-arc lamp is very large, but they differ from each other principally in details of construction. The principles of operation are about the same in all of them, and the following are not selected because they operate any better than several others, but because they will serve to bring out the points aimed at.

68. Series Enclosed-Arc Lamps for Constant Direct Current.—Fig. 33 shows the general arrangement of the

mechanism of a series enclosed-arc lamp made by the General Electric Company and designed for use on constant direct-current circuits. This figure shows the arrangement of the essential parts of the mechanism in order to bring out its method of operation, and Fig. 34 shows the general scheme of connections. In some respects, it resembles the Brush series open-arc lamp previously described. It is of the differential type, and is provided with two series coils *M* and two shunt coils *S*. In Fig. 33, only one of each of these coils is seen, as they are in line with each other. A tube *T* holds the upper and lower parts of the lamp together, and in it the carbon holder *H*, carrying the upper carbon *U*, is free to slide up and down. Current is carried to *U* by means of the flexible asbestos-covered cable *C*, which follows the carbon up and down through a slot cut in one side of the tube. The rocker is made up of two levers, *a* hinged at *a'* and *b* hinged at *b'*. These levers are connected by a spring *c* that will allow one armature to move independently of the other to a slight extent and make the action of the lamp steadier. The iron armatures *d* and *e* are carried by these levers, as shown, and when one moves up the other

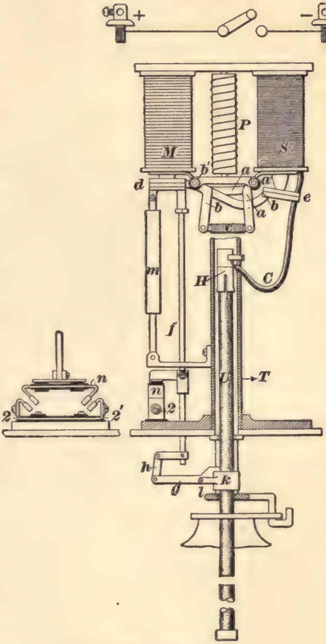


FIG. 33.

moves down a corresponding amount. Each armature is provided with two holes, through which the conical pole pieces project when the armature is pulled up. The clutch rod *f* is attached to but insulated from the rocker *a*, and is fastened to the clutch *g* through the small link *h*. The rocker and clutch are shown in about the position they

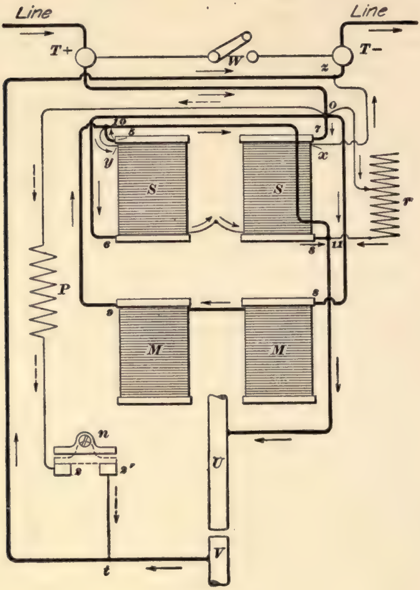


FIG. 34.

occupy after the lamp has just been started. When the lamp is out of circuit, armature *e* is up at its farthest position and armature *d* is down, the clutch ring *k* rests on the tripping table *l* and the carbons are together. A dashpot *m* is provided to steady the action of the lamp, and the cut-out preserves the continuity of the circuit and protects the

shunt coils in case the carbons should fail to feed or should be broken. The cut-out consists of a crosspiece *n* carried by the clutch rod, but insulated from it, and provided with silver contact pieces. Below the crosspiece, two insulated contacts *2*, *2'*, also tipped with silver, are arranged. When the current in the shunt coils becomes excessive, the armature *e* is pulled up so far that *n* is brought into contact with *2*, *2'* and the lamp is cut out, unless the carbons feed down so as to enable it to start again.

69. By referring to the diagram, Fig. 34, the action of the lamp under normal conditions will be understood. The coils *M*, *M* are provided with a single winding of heavy wire that is capable of carrying the current used on the circuit. The coils *M*, *M* are here shown below *S*, *S* for the sake of clearness, but it will be understood that the two pairs are opposite each other, as shown in Fig. 33, and oppose each other by pulling on the armatures of the rocker. The bulk of the winding on coils *S*, *S* consists of a large number of turns of fine wire. This winding is in shunt with the arc, and its terminals are shown at *x*, *y*. In addition to this shunt winding, each coil *S*, *S* is provided with a few turns of heavy wire, the terminals of which are shown at *5*, *6*, *7*, and *8*. These coils are in parallel with the main coils *M*, *M* and are known as compensating coils; *r* is an adjustable resistance in shunt with the series coils to enable the current passing through them to be adjusted. The resistance *P* is connected in series with the cut-out, as shown, and is used to enable the lamp to start up, as previously explained in connection with the Brush and Wood lamps. The switch *W* is provided to short-circuit the lamp when it is desired to cut it out of circuit.

70. When the lamp is not burning, the weight of the moving parts causes the armature *e* to come up against *S*, Fig. 33, the carbons are in contact, the clutch *k* rests on the tripping table *l*, and *n* is in contact with *2*, *2'*. As soon as the current is turned on, part of it takes the path *T*+–*0*–*P*–*2*–*n*–*2'*–*t*–*T*, Fig. 34. On account of the resistance *P*,

however, the greater part will take the path *T+-0-8-9-10-11-U-V-t-T*, because the carbons are, at the start, in contact. This will energize the series coils *M*, *M*, and the armature *d*, Fig. 33, will be pulled up, thus cutting off the current through the resistance *P* by raising *n* off *2*, *2'*. A certain amount of current also passes through the coarse-wire coils wound under *S*, *S* from *0* to *11* and through the paths *0-6-10-11* and *0-7-11*, but the coils *M*, *M* are so much more strongly magnetized than *S*, *S* that the armature *d* is pulled up against the attraction exerted on *e*, Fig. 33. As soon as the armature *d* is drawn up by the series magnets, the carbons are separated and current then flows through the shunt winding by the path *10-y-S-S-x-z-T*; the shunt coils are practically connected across the terminals of the arc and, as the carbons are pulled apart, the current through these coils increases. As armature *d* is pulled up, therefore, the pull on *e* is increased and a point is soon reached where the two pulls are balanced. As the carbons burn away, *e* is raised still more, the carbons are brought nearer, and clutch *k* moves down with the carbon until finally *k* rests on the table *l*, Fig. 33, and any further downward movement of the rod *f* lowers *g* and releases the clutch. This allows the lamp to feed and armature *e* then lowers to its normal position. If the carbons should stick and the arc become abnormally long, *e* would be pulled up far enough to bring *n* in contact with *2*, *2'*. The current would then take the path through the resistance *P* and the series coils would be cut out. The shunt coils would, however, still be subjected to a small E. M. F., due to the drop through *P*, and the armature *e* would be firmly held in place. If, in the meantime, the carbon should become released and slip down, the current would take the path through the series coils and carbons in preference to that through the resistance *P*. This would bring the series coils into action and cause the lamp to start up.

71. Compensation for Heating.—In order to keep the voltage at the arc of a constant-current series lamp at a

uniform value, it is necessary to have some automatic device to compensate for the increase in resistance of the shunt coils due to the heating of the lamp. The shunt coils have a considerably higher resistance after the lamp has been running an hour or two than when the lamp is first started. Now, the voltage across the shunt coils is equal to the voltage across the arc, and if the arc is to be maintained at the same length, some means must be provided for keeping the pull exerted by the shunt coils uniform. A number of methods have been adopted to accomplish this. One common method for differential lamps is to shunt the series coils by means of a resistance having a low temperature

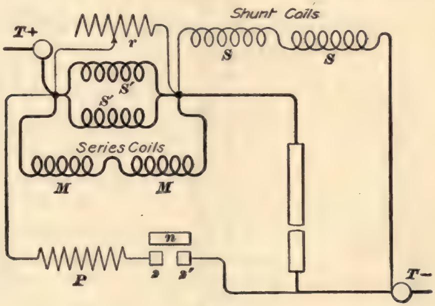


FIG. 35.

coefficient, i. e., a resistance that increases but very little with an increase in temperature. When the coils become heated, the pull of the shunt coil decreases, but the pull of the series coils also decreases, because they become heated and, being of copper, increase considerably in resistance, so that more of the current passes through the shunt having a low-temperature coefficient. Fig. 35 is a simplified diagram of connections for the lamp shown in Fig. 33. *M*, *M* are the main series coils and *S'*, *S'* the compensating coils that constitute the shunt to *M*, *M* and take an increasing amount of current from *M*, *M* as these series coils become heated. The result is, that although the pull of *S*, *S* decreases as the

lamp warms up, the balance between the shunt and series is maintained and the voltage at the arc kept at its proper value. In some cases the lamp is provided with a thermostat that closes a circuit and cuts out part of the shunt coil,

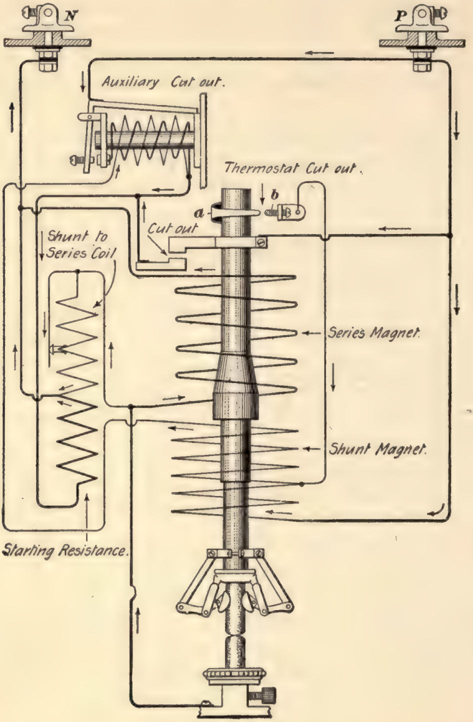


FIG. 36.

thus decreasing its resistance, when the lamp becomes hot. Fig. 36 shows the connections of the Gilbert enclosed-arc lamp for constant-current circuits. This is a differential lamp using a thermostat to cut out part of the shunt coil

when the lamp becomes hot. The thermostat consists simply of a curved strip of metal attached to the frame of the lamp. When the frame becomes heated, the expansion of the strip *a* brings it into contact with *b*, thus cutting out part of the shunt coil. In this lamp, the shunt and series coils are arranged one directly above the other and act on a movable core that operates the clutch. From what has been said regarding the lamps previously described, the student should be able to trace out the circuits in Fig. 36. The adjustable resistance, like that of all the other lamps described, is in parallel with the series coil and is used to adjust the length and, hence, the voltage of the arc.

72. Fig. 37 shows the general appearance of a Wood series enclosed-arc lamp. This lamp is provided with a regular carbon rod, instead of a carbon feed, and therefore must be provided with a chimney *A*. This figure shows the general arrangement of the enclosing globe with its gas cap.

In enclosed-arc lamps of the carbon-feed type there is always a considerable length of the upper carbon that cannot be fed down. This, however, does not involve any waste, as the length of upper carbon left over is sufficient for use as a lower carbon when the lamp is retrimmed.

Series constant-current enclosed-arc lamps of the types just described usually operate at 6.6 amperes with a voltage of about 72 across the arc. The lamp shown in Fig. 35 uses ½-inch solid carbons and burns from 100 to 120 hours without retrimming. In alternating-current lamps the top carbon is cored and the bottom solid.

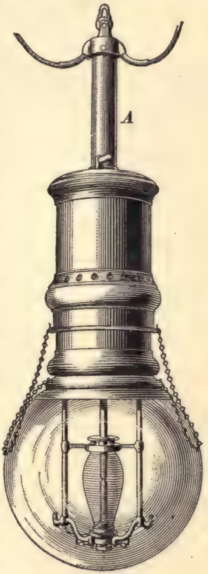


FIG. 37.

73. Series Alternating-Current Enclosed-Arc Lamps. These need no special description, as their principle of operation is exactly the same as the direct-current lamp. They are nearly always of the differential type, and the main difference is in the few constructional details referred to in previous articles.

CONSTANT-POTENTIAL ARC LAMPS.

74. As soon as the enclosed arc was introduced, it almost immediately replaced the open arc for constant-potential work. We will therefore confine our attention, in considering constant-potential lamps, to the enclosed type. The great advantages of the enclosed-arc lamp for this work are the high voltage and small current required, which enables them to be operated singly across the mains, also the soft, steady light and the long life of the carbons.

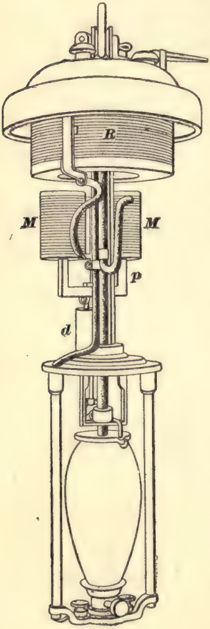


FIG. 38.

75. The mechanism of the constant-potential enclosed-arc lamp is, as a rule, very simple. The feeding is controlled by a magnet connected in series and there is no need of a cut-out. The lamp should, however, be connected to the circuit through fuses, so that it will at once be disconnected in case of a short circuit anywhere in the mechanism. The series-controlling magnet is usually arranged so that it attracts a core or plunger against the action of a spring or, more commonly, against the action of gravity.

76. Direct-Current Constant-Potential Enclosed-Arc Lamps.—Fig. 38 shows a lamp that is similar in many respects to the constant-current lamp previously described. The general features, such as the framework, clutch, method of carrying current into the upper carbon, etc., are the same in both. The magnets *M* are in series and arranged

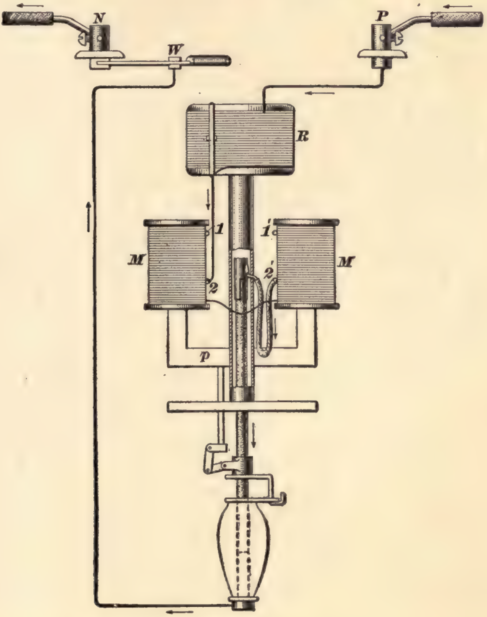


FIG. 39.

so as to pull up the plunger *p*. This plunger operates the clutch rod and its movements are dampened by means of the dashpot *d*. *R* is the resistance wound on an insulating cylinder and connected in series to take up the excess voltage and steady the action of the lamp. Fig. 39 shows the general arrangement of the mechanism and gives the

connections, which are very simple. Notice that the switch W cuts out the lamp by opening the circuit through it, not by short-circuiting it, as in the case of constant-current lamps. Current enters at P and flows through the resistance and series coils to the upper carbon, thence to the lower carbon to N. This causes the core to be pulled up and the carbons to be separated. As they burn away, the current becomes weaker and p gradually lowers until the clutch is released and the lamp feeds. The resistance is provided with a sliding contact, so that the lamp may be adjusted for pressures varying from 100 to 120 volts. The series coils are provided with two connections *1*, *1'* and *2*, *2'*, so that the lamp may be made to operate at 4½ to 5 amperes or 3¼ to 4 amperes. When the larger current is used, the connections are as shown in the figure, because fewer turns are then needed to operate the plunger. Solid carbons ½ inch in diameter are generally used, and the voltage at the arc is about 80, leaving 20 to 40 volts to be taken up in the resistance. With ½-inch carbons, the lamp will burn 130 to 150 hours without retrimming.

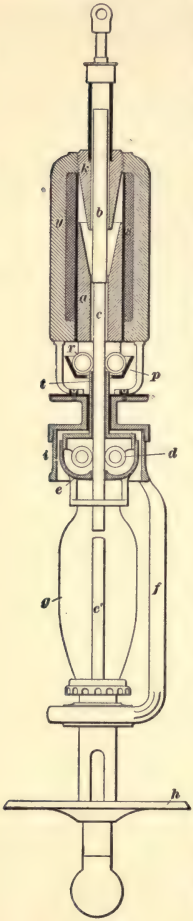


FIG. 40.

77. Fig. 40 shows another form of constant-potential enclosed-arc lamp, of which there are a large number in use. This lamp is very heavily constructed, and has a rather peculiar clutch and contact arrangement for carrying the current into the upper carbon.

There is but one solenoid *s*, which is connected in series with the carbons and has a compact magnetic circuit through the yoke *y*, the conical core *k*, and the armature *a*. The armature carries at its lower end a pan *p* containing four clutch rings *r* that fall by gravity and grip the carbon *c* by wedging between the carbon and the inclined side of the pan. As the carbon falls by reason of the consumption at the arc or through the current being interrupted, the pan is lowered until the rings are caught by the tube *t*, which is supported by the frame of the lamp. This action releases the carbon, which then falls towards the lower carbon *c'*, but the consequent reduction of resistance causes a large current to flow through the coil *s*, which draws up the armature, and with it the carbon *c*, to the normal height. Regulation is, then, effected by the differential action of a series coil and gravity, for the moving system is designed to have considerable weight. The upper carbon is held in a sheath *b*, which permits the using of shorter carbons than would otherwise be necessary. The sheath will readily pass between the clutch rings and through the tube *t*. The current is conducted to the carbon by means of sixteen contact rings *d*, enclosed within a box *e* and making a flexible contact with the carbon. The inner globe *g* surrounds the carbons and is supported by the arm or yoke *f*. The outer globe fits over the plate *h* at the bottom and is secured at the top by a circular nut at *i*, the joint being packed by means of asbestos gaskets. The space immediately above *h* and below the inner globe is intended for the rheostat. In the later styles of this lamp the rheostat is placed in a small metal case at the top of the lamp.

78. Alternating-Current Constant-Potential Enclosed-Arc Lamps.—Fig. 41 shows the arrangement of an alternating-current constant-potential lamp. The general appearance of the lamp is almost exactly the same as that shown in Fig. 38. The principal distinguishing feature of the alternating-current lamp is the use of the reactance, or

choke, coil L in place of the resistance. This consists of a laminated iron core a on which coils b are wound. These coils are connected in series and the ends *1*, *2*, *3*, *4*, etc.

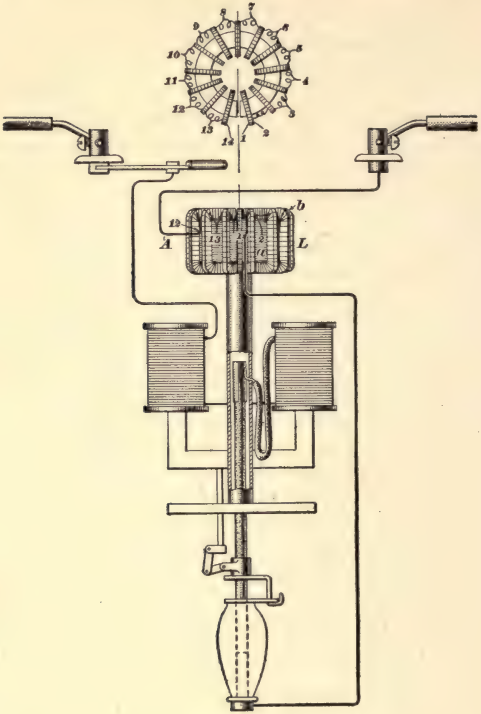


Fig. 41.

left so that the wire A may be connected at different points. This allows the lamp to be adjusted for a considerable range of voltage and frequency. The reactance coil sets up a counter E. M. F., and thus introduces an

apparent resistance into the circuit which counterbalances the excess voltage and makes the lamp stable in its operation. The reactance coil is more economical than a resistance, but it and the series magnets introduce self-induction into the circuit and thus make the lamp have a power factor less than 1. A load of alternating-current arc lamps is always inductive, and this has in some instances been used as an argument against them. They are, however, well adapted for stations already equipped with alternating-current apparatus and where it is desired to operate arc lamps with the least expense for additional equipment. The frequency should not be below 60 cycles per second for satisfactory operation.

The lamp just described will operate anywhere from 60 to 140 cycles. It takes about 72 volts at the arc and burns from 80 to 100 hours. The upper carbon is cored and the lower carbon solid.

79. Connections for Constant-Potential Lamps.— Fig. 21 shows constant-potential lamps connected across a 110-volt circuit. Each lamp should be connected to the mains through any good style of double-pole fuse block. In most cases, it is also desirable to equip each lamp with a switch in addition to the switch that is on the lamp itself, as this switch is not always easily accessible. Where separate switches are used, they should be double-pole if the lamp takes more than 3 amperes. In connecting up constant-potential lamps, the branch wires should be proportioned for at least 50 per cent. more current than the lamp takes, because at starting the current may be much in excess of the normal. Fig. 22 shows constant-potential alternating-current lamps connected on a 104-volt alternating-current circuit. The connections are practically the same as those shown for the direct-current circuit, except that the lamps are here fed from the secondary of the transformer. Enclosed arcs are also made for operation on 220-volt circuits, but these high-voltage lamps are not as efficient as those for lower voltage.

Enclosed arcs are sometimes operated two in series on 220-volt mains, or four or five in series on 500-volt mains where it is desired to operate a few arc lamps from a power circuit. This method of operation is, however, not as satisfactory as when each lamp is independent and it is only adopted in case of necessity.

CARE AND ADJUSTMENT OF ARC LAMPS.

80. General Remarks.—If an arc lamp is kept clean, and if the current and voltage at which it is operated are maintained at the values for which it is designed, it will give little trouble. This assumes, of course, that the lamp is substantially made. Cheapness seems to be the principal object in some lamps, and while the first cost of such is low, the bill for repairs is heavy and they are much the more expensive in the long run. The older styles of open-arc series lamps were usually heavily built and, as a rule, gave good service. We will first consider some points in connection with lamps of this class.

81. Trimming.—Most open-arc series lamps are provided with a carbon rod on which the clutch operates. If this rod is dirty or greasy, the clutch will not work properly and the lamp will give poor service. When trimming the lamp, the rods should never be pushed up when they are in a dirty condition.

Dirt on the rod is apt to cause pitting, due to the burning action of the current where it passes into the rod from the contact spring or bushing. If the rods are at all dirty, they should be rubbed down with a piece of worn crocus cloth. When trimming the lamp, care should be taken to see that the carbons are of the proper length. Lack of care in this particular is often responsible for burned carbon rods and carbon holders. The carbons should be placed so that they are vertically in line with each other, and the upper

carbon must have enough vertical play to allow the lamp to pick up its arc.

82. Adjustments.—The principal points to look out for in adjusting an arc lamp are to see that the arc burns at the proper length and that the carbon is fed down smoothly without any hissing or flickering. For an ordinary 1,200 nominal candlepower open-arc lamp, the arc should be about $\frac{3}{64}$ inch in length; for a 2,000 candlepower, from $\frac{1}{16}$ inch to $\frac{3}{32}$ inch. The exact length will depend somewhat on the quality of the carbons. If the arc is too short, it is liable to hiss, or if the current is too large, hissing is apt to result. An arc that is too long will flame badly and the lamp will take more voltage than it should. Poor quality of carbons will also cause flaming or hissing. The length of arc and the feeding point may be regulated by proper adjustment of the clutch. Directions for adjusting each particular make of lamp are furnished by the makers, but as a rule such adjustments are easily learned by an inspection of the lamp itself. In some cases the clutch and rod may become so worn that they must be replaced before a satisfactory operation can be obtained.

A good method to follow in adjusting lamps is to connect an ammeter in series and a voltmeter across the terminals of the lamp. The first thing to look out for is to see that the dynamo is maintaining the proper current in the circuit. If it is not doing so, the regulator on the dynamo should be adjusted until it does. The lamp should be hung in some place where it will not be exposed to drafts of air, because such drafts may cause the arc to hiss or flame even if it is properly adjusted. A rack should be provided for supporting the lamps at such a height that the mechanism may be easily inspected. By watching the fluctuations of the voltmeter as the lamp burns, a good idea may be formed as to the smoothness with which the lamp feeds. A recording voltmeter is very convenient for this work, as the lamp may be left to itself for some time, and the voltmeter will draw a chart indicating the variations in voltage during

the time. If the voltage goes very much above or below the normal, the voltmeter record will show it at once. The lamp man knows from experience just about what the type of lamp he is working with is capable of doing in the way of feeding closely, and he can tell at a glance whether the performance can be improved.

83. Burned-Out Coils.—The controlling coils of series arc lamps are frequently burned out and have to be rewound. Burn-outs may arise from a number of different causes. Lightning is frequently responsible for them, as it breaks down the insulation of the lamp or punctures the insulation between the layers of the winding. One of the most frequent causes of burned-out shunt spools is a defective cut-out. If the carbons stick and the cut-out fails to work, the arc grows so long that the current in the shunt coils becomes excessive, and they are sure to be burned out. The cut-out contacts should be kept in good condition, and if burned or oxidized, they should be carefully cleaned. Neglect to look after the cut-out part of the lamp will surely result in the rewinding of shunt spools, and as these are wound with fine wire they are a comparatively expensive part to repair. In some lamps the action of the cut-out depends on the movement of the rocker, for example, the T. H. lamp; hence, it is important to see that the frame moves freely. If the lamp is improperly adjusted so that it burns with an abnormally long arc, the current through the shunt will be greater than it should be. This will cause the coils to overheat, and while it may not result in a burn-out at once, it is very apt to lead to it in time by causing deterioration of the insulation and consequent short circuiting between layers. A similar result may be caused by the line current being above the normal, and in this case the series coils would also be affected. Generally, however, the series coils will stand a reasonable overload without greatly overheating. Series lamps should cut out promptly, if the upper carbon is pushed up while they are burning. If they do not do so, there is something wrong with the

cut-out and the trouble should be remedied before the lamp is sent out.

84. Most of the above also holds true with regard to series enclosed arcs. There is even more danger of the carbon sticking and failing to feed properly in these lamps than in the open arcs, because the carbon must pass through the cap of the enclosing globe, and if the carbon has not been gauged beforehand, a slight unevenness may cause it to stick. It is therefore important to see that the cut-out is kept in good condition and that there are no uneven places on the carbons when they are put in the lamp.

85. Trimming Enclosed-Arc Lamps. — Generally speaking, it is necessary to clean the enclosing globe every time the lamp is trimmed. If it is allowed to go longer without trimming, it becomes covered with such a thick deposit that a considerable part of the light is cut off. This cleaning can be done to much better advantage at the station than at the point where the lamp is installed, so that the lower globes are brought back to the station for retrimming and are there washed by means of special appliances for the purpose. When the trimmer goes out, he takes a clean lot of globes, provided with lower carbons, and replaces the old ones. Care should be taken to see that the carbons used are of the proper length. The upper carbons are purchased in the desired length, but the lower carbons are very often made up of the part left over from the top carbon. These pieces will vary in length, and they should be cut to gauge before being placed in the bottom holders. The upper carbons should all be gauged to make sure that they will pass through the cap freely. For a ½-inch carbon, the maximum allowable diameter is about .52 inch and the minimum diameter .5 inch. If the carbon is smaller than the allowable amount, there will be too much air admitted to the enclosing globe and the arc will flame badly. Only the best quality of carbons should be used in enclosed-arc lamps, otherwise the enclosing globe will become thickly covered with deposit. Attention should be paid to

the gas caps of enclosed-arc lamps and also to the joint between the globe and the bottom carbon holder. If there is too much air admitted, the carbons will be consumed rapidly. If the globes are too tight, very little air will be admitted and the unconsumed carbon will be deposited on the globe.

86. Since most enclosed-arc lamps have a carbon feed, it is necessary to see that the carbons are smooth, because rough spots will interfere with the operation of the clutch. If necessary, rough spots should be smoothed down with sandpaper. Constant-potential lamps have no cut-out to give trouble, but they have a resistance coil that fully counterbalances the cut-out in this respect. If the carbons stick and fail to feed, the lamp goes out, but if the lamp does not pick up properly, the carbons being in contact, the resistance offered by the arc will be absent and a current much larger than the normal will flow. If the fusible cut-out in series with the lamp does not blow, the resistance will be very liable to overheat and burn out. There is also danger of the insulation on the series controlling magnet being damaged, It is a common occurrence to find constant-potential lamps that have been designed and adjusted for 104 to 110 volts running on circuits where the voltage is as high as 125 or 130. Of course, under these circumstances the lamp takes a current larger than it should, and it must not be forgotten that the heating effect in the resistance coil and other parts of the lamp runs up as the square of the current. A comparatively slight increase in the current will, therefore, result in quite a large increase in the heat developed, and this in the course of time is sure to result injuriously. An abnormal current is also liable to melt the enclosing globe. Of course, many of the burn-outs on these lamps may be traced to faulty design or construction, but at the same time it is quite true that many good lamps give trouble either because the voltage is too high or because the lamp has not been properly adjusted to suit the voltage on which it is to operate.

LINE WORK FOR ARC LIGHTING.

SERIES SYSTEMS.

87. Size of Wire.—Since most outside lighting work is done on the series system, and the current being usually not greater than 9.6 amperes, the line wire does not need to be large. Generally, such lines are of No. 6 B. & S. double- or triple-braided weather-proof wire. Triple-braid wire of this size weighs about 585 pounds per mile; double-braid wire weighs about 510 pounds. Its resistance per mile is approximately 2.08 to 2.12 ohms. Sometimes No. 8 wire is used for arc lines, but while it is large enough to carry the current, it does not make as substantial a job as the No. 6. The difference in first cost between the two sizes is not great and, as a general rule, it will pay to put up the larger wire, especially in localities where sleet storms are common.

88. Since the current is small, series arc lines may be run long distances without having an excessive loss. For example, with a 9.6-ampere current, the drop per mile of wire would be about $2.08 \times 9.6 = 19.97$ volts. Series arc circuits often extend for miles, but the extension of the line simply cuts down the pressure available for the lamps, so that a given dynamo is not capable of operating quite as many lamps on a long circuit as on a short one.

89. Laying Out Arc Circuits.—There is, generally, not a great deal of choice as to the laying out of an arc circuit for street lighting, as it is determined almost altogether by the location of the lamps. At the same time, wire and labor can often be saved by laying out a plan of the streets to be lighted and then arranging the circuits so that the line will pass through one lamp after another with as little doubling back on itself as possible.

When laying out the line, it is a good plan, where possible, to connect the terminals of a loop in the circuit to a switch so that, in case of trouble, the loop may be short-circuited

and the remaining lamps on the circuit continued in operation. Fig. 42 will illustrate this; *l*, *l*, *l* represent arc lamps connected on a street circuit, as shown. By putting in switches at points *A*, *B*, the loops in the circuit may be cut out. For example, if a break occurred, as indicated at *x*, the switch *A* could be closed and the rest of the lamps kept going while the break was being located. It is also evident that a few switches arranged in this way would be of assistance in locating breaks. In Fig. 42, plain short-circuiting

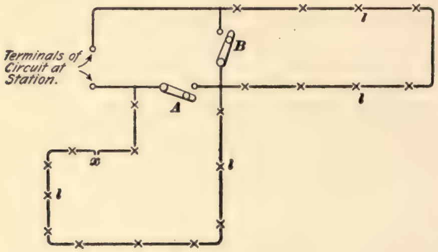


FIG. 42.

switches are indicated in order to bring out the method in view and to simplify the figure. In practice, a switch should be used that will provide a path around the loop and at the same time disconnect the loop entirely from the remainder of the circuit, so that it may be worked on and the fault located without danger to the linemen. These loop switches are usually mounted on a pole or at any other point where they will be accessible.

90. It is preferable to have separate lines for operating the commercial lights and street lights, because lamps used in places of business usually have to be started earlier and extinguished earlier than those used on the streets. Moreover, it may be necessary to run store lights for a short period in the morning, when no street lights are needed. Another argument in favor of separate circuits for the

commercial lights is that the long-exposed street circuits are always more or less subject to breaks or other troubles, and this would be liable to interfere with the regularity of the service given by the commercial lights.

No matter how carefully street arc-light circuits are laid out in the first place with a view to economizing copper, they soon become very irregular if the number of lights is at all increased. Lights are looped in here and there, and the result is that the general layout of the circuits assumes a very different appearance from what was originally intended.

LINE CONSTRUCTION.

91. Line construction for arc lighting is generally carried out, in the ordinary way, by stringing the lines on poles. In some cities, considerable arc lighting is carried out by underground distribution. For this purpose, heavily insulated, lead-covered cables are used. In all construction work connected with series arc circuits, the point must not be lost sight of that the pressure across the terminals of these circuits is very high and that there is always a strong tendency for grounds to develop. A large size of deep-groove double-petticoat insulator should be used and the wires kept clear of trees. Great care should be taken when wires are run near metal awnings at the entrance to stores, etc., as this is a place where grounds are apt to occur and where, in a number of cases, they have resulted in fatal accidents. The necessity for high insulation and careful work in connection with arc lines is even greater than it once was, when about 50 lights on a circuit was a common average. Now the number of lights per circuit is often over 100, and if the lines are not kept in good condition there is sure to be trouble. All fittings used about the lamps themselves should be such as to give high insulation.

92. Height of Lamps.—Arc lamps for street lighting are nearly always placed at street intersections. When the

blocks are long, they are also placed in the middle of the block. The older method was to use a comparatively small number of lamps hung high above the street, but it is now considered better practice to hang the lamps lower and to use more of them if necessary. This is especially the case when the streets are shaded by trees. Where the space to be illuminated is open, the lamps may be hung fairly high, say 30 to 40 feet above the ground; but

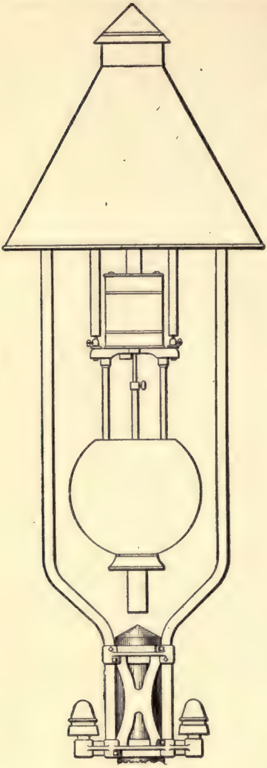


FIG. 43.

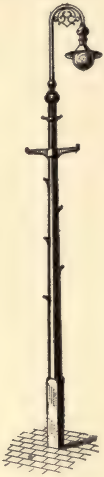


FIG. 44.

when the streets are at all shaded, a height of 20 to 25 feet is to be preferred.

93. Methods of Hanging Lamps.—There are, in general, three methods of hanging lamps: (*a*) By mounting on

pole tops; (*b*) by suspending from mast arms or pole fixtures projecting from a side pole; (*c*) by suspending from the middle of a span wire so that they will hang over the middle of the street.

When the lamps are mounted on **pole tops,** they are fixed permanently, no provision being made for lowering them when they are trimmed. The pole must, therefore, be provided with pole steps, so that the trimmer may climb up to the lamp. This method of mounting makes the work of trimming hard, and it is, therefore, not used nearly so much as other methods, which allow the lamp to be lowered for trimming. Fig. 43 shows a lamp with the pole-top mounting. It is necessary to provide a hood to protect the top of the lamp. With the older styles of lamp, these hoods were large enough to accommodate a **hanger board,** from which the lamp was suspended. In the newer lamps, a much smaller hood is sufficient. This method has a few advantages, among which are the absence of rope and pulleys, also the line wires when once connected up are not moved, as they are every time a lamp is raised or lowered. The raising and lowering of lamps is a frequent source of breaks in the line wire due to the slight bending and unbending that the wire is subjected to. These advantages are, however, more than offset by the difficulty of trimming if the lamps are mounted high above the street. Fig. 44 shows a more ornamental style of pole-top mounting. In this case, the lamp is only about 20 feet above the street, and as it is used with enclosed arcs, which are trimmed about once in a week or ten days, the climbing up to the lamp is not as much of an objection as when open arcs, requiring daily trimming, are used.

94. Fig. 45 illustrates a typical mast-arm suspension. The general arrangement will at once be seen from the figure. The lamp is raised and lowered by means of a rope and pulleys, and is provided with a small hood *b* to protect the top from the weather. The lamp is suspended from the rope by the intervening cross-arm *a* and

insulator *b*. A cross-arm and insulator of this kind should be provided in order to secure good insulation between

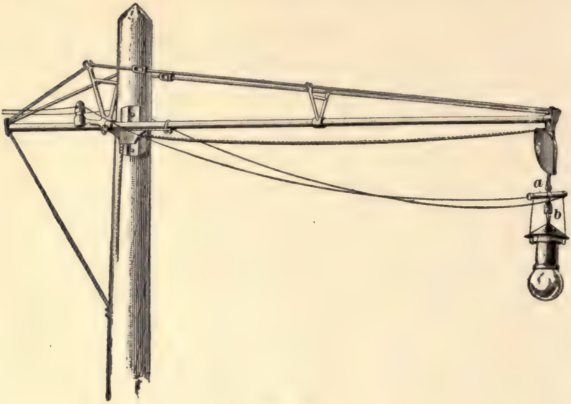


FIG. 45.

the lamp and the pole fixture and also to keep the line wires spread apart.

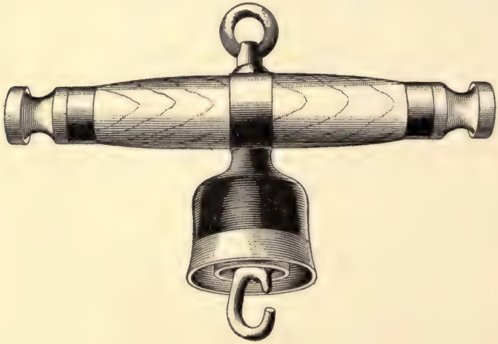


FIG. 46.

Fig. 46 gives a view of a Cutter insulating cross-arm Since the introduction of high-voltage enclosed arcs and the operation of a large number of lamps per circuit, it is essential that each lamp be provided with a suspension that will give high insulation. The old-style, plain, wooden crosspiece with a porcelain knob at each end is hardly sufficient.

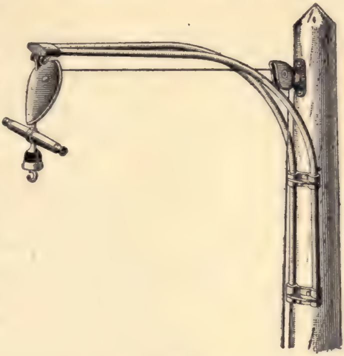


FIG. 47.

Some styles of mast arm are pivoted at the pole and are counterbalanced so that the arm may be swung down for trimming.

Fig. 47 shows a Cutter pole fixture of small size that has been used considerably for street lighting with enclosed arcs. It supports the lamp about 3 feet from the pole.

95. The span-wire method of suspension is illustrated in Fig. 48. It is the best form to use when it is desired to

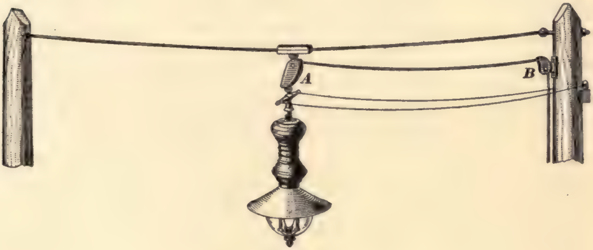


FIG. 48.

bring the lamp over the center of the street. A pulley is placed at the center and another on the side pole and the

poles are usually set at diagonally opposite corners of the street intersection. The span or suspension wire is usually of $\frac{5}{16}$-inch or $\frac{3}{8}$-inch galvanized steel and the side poles about 30 to 35 feet high with a 6-inch top. This method of suspension, of course, involves the use of two poles and for this reason the mast-arm suspension is often preferred. The chances are that for lighting a given town or city a combination of the three may be desirable, the style of suspension being chosen that is best adapted for the particular location of the light.

96. Arc-Lamp Pulleys.—Pulleys used for suspending arc lamps have received a great deal of attention at the hands of those especially interested in arc-lamp specialties. The ordinary style of pulley is not well adapted for this kind of work. An arc-lamp pulley should always be provided with a hood to prevent its being clogged by sleet. It is also desirable that the pulley from which the lamp is hung be of such a design that it will hold the lamp from dropping in case the rope breaks or becomes unfastened in any way. In Fig. 48, a lamp-supporting pulley is indicated at *A* and a swivel-pole pulley at *B*. Both are of the sleet-proof kind. A number of different types of lamp-supporting pulleys are now manufactured. In most of them either a catch or projections are arranged inside the pulley casing so as to hold the lamp when it is raised and relieve the rope of all strain. When the lamp is to be lowered, it is first pulled up a little. This unlocks the pulley and allows the lamp to be lowered. The use of self-locking pulleys also helps to make the operation of trimming more rapid.

Arc-lamp pulleys have also been brought out that contain a switch that cuts off the lamp entirely from the circuit when it is lowered. This allows the lamp to be lowered without lowering the wires running to it, and also makes it perfectly safe to work on. These pulleys are, however, somewhat complicated.

97. Rope.—The rope used for raising and lowering the lamps is an important item on a large system and it should

be carefully selected. Practice varies greatly as to the kind of rope used. Formerly, manila rope was used almost exclusively, but the tendency is now towards a solid braided cotton rope or a flexible wire rope. When cotton is used for this purpose, it is provided with a wax finish that keeps the rain from soaking into and rotting it. This rope is usually $\frac{5}{8}$ inch in diameter, though $\frac{1}{2}$ inch is sometimes used with heavy lamps. If wire rope is used, it is usually the so-called tinned "sash cord," which is a rope made up of a hemp center surrounded by tinned steel wire. When a metal rope is used, an insulator should be cut into it at a point just outside the pole pulley in order to insulate the trimmer's end of it. When the lamps are very heavy, a small windlass is frequently used to hoist them.

98. It was formerly the practice to coil up enough surplus rope on the pole at each lamp to allow the lamp to be lowered to the ground. It is now customary to end the rope in such a way that another rope may be hooked on to it and the lamp lowered. This extra rope, known as a **trimmer's rope,** is from 20 to 30 feet long and is provided with a snap hook at one end and a number of rings near the other, the latter being spaced so as to suit the varying heights at which the lamps may be hung. The end of the rope on the pole may be fastened by means of special pole padlocks, made for the purpose, but in many cases it is simply slipped over a pin, as shown in Fig. 49. The use of the lock is, however, safer, as it prevents the lights from being tampered with.

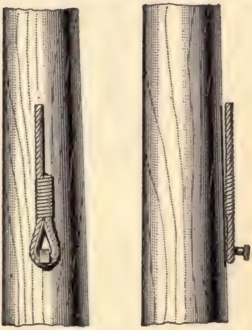


FIG. 49.

99. Cut-Out Switches.—The rules of the Fire Underwriters require that wherever constant-current arc wires

enter a building, an approved double-contact service switch shall be installed, so that the current may be cut off at any time. These switches must be substantially made, must be mounted on incombustible bases, and must be placed where they may be easily reached by policemen and firemen. There are many different types of these cut-out switches, but they should all have good contacts and be quick in action. The switch must also show clearly whether the current is on or off.

Fig. 50 shows the working parts of the Wood arc cut-out, a style that has been extensively used and which will serve to

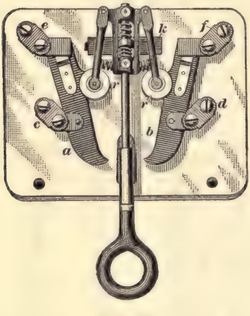


FIG. 50.

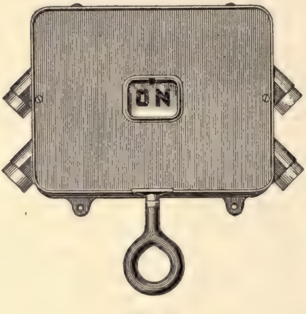


FIG. 51.

illustrate the operation of cut-out switches in general. The parts here shown are mounted in a waterproof cast-iron box with an opening past which an indicator moves to show when the current is on or off.

Fig. 51 shows the external appearance of the switch. Two blades *a*, *b*, Fig. 50, are attached to the line terminals *c*, *d*, as shown. The house terminals are connected to the posts *e*, *f*. When the handle is pushed up, the porcelain rollers *r*, *r* press the blades into the clips on terminals *e*, *f* and thus connect the line with the lamps. When the lever is pulled down, the rollers bear on the lower part of the blades, causing them to leave the clips on the posts *e*, *f* and swing over so as to rest on the casting *k*, thus cutting

out the lamps and allowing the current to flow directly across from one blade to the other and disconnecting the house wires entirely from the line. The springs shown in the figure make the action quick and positive.

100. Cut-Outs on Arc Lamps.—Nearly all arc lamps are provided with a simple short-circuiting switch by means of which the lamp may be cut out. This switch does not, however, disconnect the lamp entirely from the circuit, and it is always dangerous to work on a lamp under such circumstances when standing on the ground, because there is liable to be a ground on some part of the line and thus establish a path for the current through the person working on the lamp. Since the introduction of constant-current circuits operating a large number of lights, the danger from shock has materially increased, and to get around this, lamps are now frequently equipped with individual cut-out switches that are separate from the lamp and that will cut out the lamp and disconnect it entirely from the circuit. Fig. 52 shows a series arc lamp equipped with a separate cut-out switch of this kind.

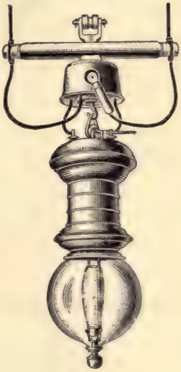


FIG. 52.

101. Looping in Lamps on Series Circuits.—When a lamp is looped in on a series circuit out of doors, it is not necessary to provide a cut-out switch at the point where it is cut into the line, though, as mentioned in the previous article, switches are sometimes placed at

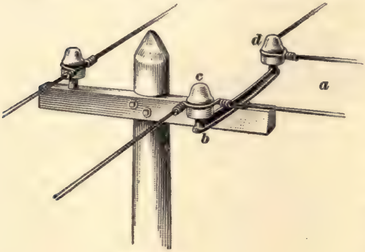


FIG. 53

the lamp itself. Fig. 53 shows one method of looping in on a series circuit. An arm *b*, provided with insulators *c*, *d*, is mounted as shown. The loop *a* runs to the lamp or, in case the circuit is carried into a building, runs to the cut-out. Fig. 54 shows another method, which is not quite so neat, but does not call for the use of a special bracket. The break in the circuit is made by using two ordinary porcelain insulators *m*, *n* and a double-petticoat glass insulator *i*. When a circuit is to be looped in between poles, the break may be made by using

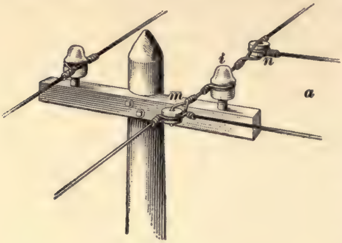


FIG. 54.

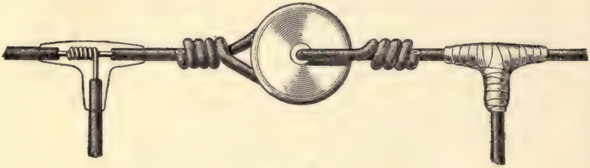


FIG. 55.

a single porcelain insulator, as shown in Fig. 55, or if higher insulation is required between the terminals of the break, two insulators connected by a short length of wire may be

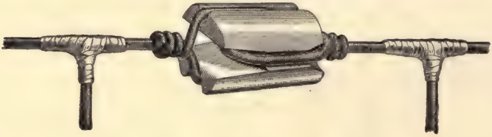


FIG. 56.

used. Fig. 56 shows another method of accomplishing the same result by using a special porcelain insulator that is made for this purpose.

SPECIAL APPLICATIONS OF ARC LAMPS.

102. Before leaving the subject of arc lamps we will take up, briefly, a few of the special applications to which the arc lamp has been put. Arc lamps are extensively used for stage illumination in theaters, for photo-engraving work, blueprinting, searchlights, or, in fact, any work where a strong light is necessary. For most of this work,

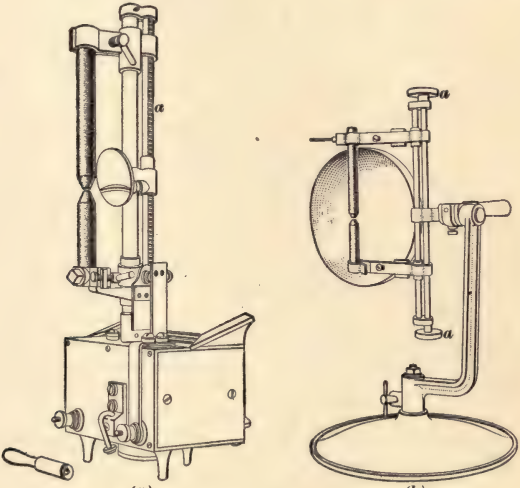


FIG. 57.

the ordinary styles of arc lamp are not suitable, because such lamps are not of the focusing type. For projection work, it is necessary to keep the arc in a fixed position; in some cases this is accomplished by hand feeding, while in others the feeding is automatic. In Fig. 57, (*a*) shows an automatic focusing lamp and (*b*) a hand-feed focusing

lamp. The lamp (*a*) is usually mounted on a stand and provided with accessories to suit it to whatever kind of work it is used for. It is designed for 20 amperes and is operated on direct-current circuits of 75 to 125 volts. The hand-feed lamp shown at (*b*) also operates normally at 20 amperes, but by using larger carbons, currents up to 50 amperes may be employed. The hand-feed lamp may also be operated with alternating current, but the alternating current is not very satisfactory for use in projection work. The hum caused by the arc is often very annoying, and, moreover, the arc is continually shifting around. In both lamps shown in Fig. 57 it will be noticed that the carbons are fed together by screws and that the rate of movement is adjusted so that the arc always remains stationary. If a lamp is to be used for short intervals only, the hand feed will be found quite satisfactory, because it is simple, cheap, and not liable to get out of order. If, however, the lamp is to be used for long runs, it is better to have an automatic feed. The lamp in Fig. 57 (*a*) is fed by the screw *a*, which is rotated by means of the lamp mechanism contained in the case below. In (*b*) the carbons are regulated by turning the knobs *a*, *a*.

103. When these lamps are run on a regular 110-volt circuit, a rheostat must be inserted in series with them in order to take up the excess voltage. The rheostat should be capable of carrying the current required by the lamp without undue heating, and should have enough resistance to give a maximum drop of about 70 to 80 volts when used on 110-volt circuits. About 20 to 30 volts of this drop should be adjustable, so that the current taken by the arc can be kept at the proper amount. For example, a lamp taking 20 amperes should have about $3\frac{1}{2}$ ohms in the rheostat, and at least 1 ohm of this should be split up into 10 or 15 sections and connected to a regular rheostat switch so that a good adjustment can be obtained. A 10-ampere lamp would require about 7 ohms in the rheostat, and 2 or 3 ohms of this should be adjustable.

SEARCHLIGHTS.

104. One of the most important applications of the arc light for projection purposes is found in the searchlight. These are now used extensively both on shipboard and also on land, and reference has already been made to the arrangement of the carbons and mirrors as used in them. A searchlight is designed to concentrate the rays emitted from the crater of the positive direction and to project them so that they will be parallel to each other. A beam of light that does not spread out will illuminate objects at great distances, because the intensity of such a beam does not fall off with the square of the distance as does the light from an ordinary source. In fact, if all the rays were exactly parallel and the mirrors perfect and if there were no absorption of light by the atmosphere, the intensity of the beam would not diminish at all. As a matter of fact, it does diminish to an extent that depends very largely on the condition of the atmosphere.

For many of the following points and illustrations relating to searchlights we are indebted to a paper by Lieut. B. T. Walling published in the Proceedings of The United States Naval Institute. The type of lamp here described is one designed by the General Electric Company and which is used very largely both for naval and commercial work.

105. General Construction.—Fig. 58 shows a 24-inch projector. The barrel *A* contains the lamp and reflector, the reflector being mounted in the back end. This barrel is swung on trunnions supported by the base *B* and is arranged so that the projector can be swung around through any angle. The barrel can also be swung up and down or clamped in any desired position by

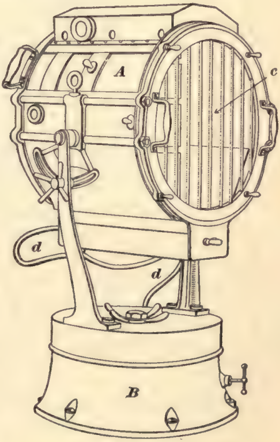


FIG. 58.

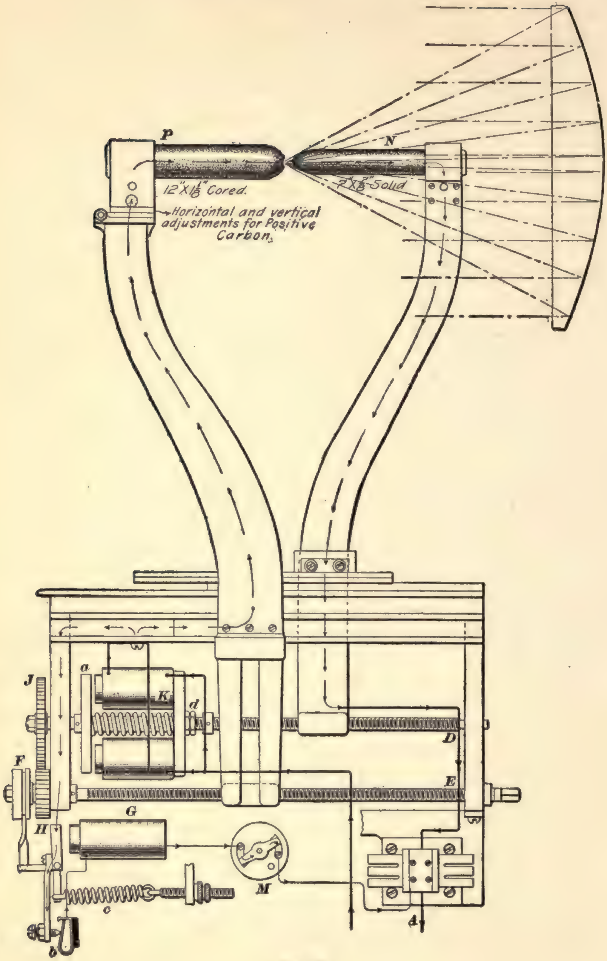

P
N
12"X1⅛" Cored.
7"X⅞" Solid
Horizontal and vertical adjustments for Positive Carbon.
a
J
K
d
D
F
E
G
H
M
c
A
b

FIG. 59.

means of the fittings shown. In this projector these movements are accomplished by hand, but in many of the projectors used for naval work the movements are brought about by small motors mounted in the base, so that, if desired, the searchlight may be controlled from a distant point by running cables from the projector to a controller situated at whatever point the searchlight is to be controlled from. The door of the projector is made of strips *c* of plate glass in order to avoid breakage and also to allow broken fronts to be easily repaired. Current is carried to the lamp by means of cables *d*, *d*, which connect to sliding contacts in the base.

106. Mirrors.—The mirrors or reflectors used in the better class of projectors are of glass, ground carefully and silvered on the back. Parabolic reflectors are used in the navy, as they throw a more powerful beam than the Mangin mirror or concave mirror. For commercial projectors, the Mangin mirror is used, and where cheap projectors are required or in case the projector has to stand a great deal of moving around, it is customary to use copper reflectors silvered on the inside surface. The lamp must be adjusted so that the crater comes at the focus of the mirror, otherwise the light will not be thrown out in parallel rays. The crater must, of course, face the mirror.

107. Searchlight Lamp.—Fig. 59 shows a type of lamp now used both for commercial and naval work. In this lamp the carbons are horizontal, the positive carbon being larger than the negative and pointing directly at the mirror. Some changes have been made in the later lamps from the construction shown in Fig. 59, but the principles involved are the same. The lamp has what is called a **ratchet feed** and is provided with two magnets—a series magnet that serves to strike or start the arc and a shunt magnet that works the ratchet feed.

Referring to Fig. 59, the shunt magnet is shown at *G* and the series magnet at *K*. *P* is the positive carbon and *N* the

negative. *M* is a small switch for cutting off the current from the shunt coil when it is desired to feed the lamp by hand. The lamp may be fed by hand by slipping on a crank wrench at *R*. Screw *D* feeds the negative carbon and *E* the positive, the two screws being geared together at *J*. Current is led into the lamp by means of two sliding contacts *A*, one of which is shown in the figure, the other being directly behind *A* on the other side of the lamp. *H* is the armature of the shunt magnet and *F* the pawl-and-ratchet mechanism by which screw *E* is turned. The lamp for a 30-inch projector takes from 75 to 90 amperes, and for an 18-inch projector the current is from 25 to 35 amperes. The working current varies with the size of the lamp and also with the size of the carbons used. The voltage required at the lamp is usually from 45 to 49 volts and the feed will frequently operate when a pressure of 50 volts is reached.

108. The method of operating the lamp is as follows: The carbons are adjusted by the crank wrench to a separating distance of about $\frac{1}{2}$ inch. The switch *M* is next closed. The main switch is closed next, and as no current can pass between the carbons, the voltage between them and, hence, the voltage across the shunt magnet *G* must be equal to the full-line voltage. The consequence is that armature *H* is attracted. As soon as *H* is attracted, the current through the shunt circuit is broken by the contact device *b* and the armature falls back and the attraction is again repeated. The armature *H*, therefore, vibrates rapidly and works a pawl that shoves the ratchet *F* around and feeds the carbons together. The screws are geared together, so that screw *D* revolves one-half as fast as *E*. As soon as the ratchet feed brings the carbons into contact, a heavy current flows for a short interval and the series coils *K* pull back the armature *a* and thus start the arc. As the carbons burn away, the voltage across *G* increases until the ratchet feed operates and moves the carbons a little nearer together. The point of feeding can be adjusted by means of the spring *c* and the length of the arc by means

of nuts *d*. The positive carbon holder is provided with vertical and horizontal adjustments, so that it can be accurately lined up.

109. Naval searchlights are usually operated on 80-volt circuits, so that it is necessary to take up but 20 to 30 volts in the rheostat. For commercial lamps, the line voltage is higher, but in any case the rheostat should be adjusted so that the lamp will operate without hissing or flaming. With the horizontal type of lamp here described there is a tendency to flame at the upper edge of the crater, thereby forming the crater on the upper edge of the positive carbon and distorting the reflection. This tendency is corrected by a horseshoe magnet, which draws down the arc.

110. Some hissing will occur when starting up, especially with new carbons, and the lamp will not quiet down until a good crater has been formed in the positive carbon. This can be obviated by reaming out a crater in the positive carbon with a penknife before putting it in the clamp. Flaming and hissing are promoted by inferior carbons and are much increased if the carbons have absorbed oil. Carbons should be hard, homogeneous, and of the best quality. Soft carbons fuse and form "mushrooms," which cut off a large portion of the light and make the arc unsteady. The positive carbon should be cored, as this assists in holding the arc central and in making a good crater. Negative carbons are sometimes cored, but this is not generally considered necessary or even desirable.

111. Points Relating to Care and Operation.— When the searchlight is first started, an abnormal current will flow for an instant when the carbons touch each other. This current may be sufficient to throw the ammeter off the scale, but it does no particular harm if it does not continue. If it should continue, on account of the lamp failing to work properly, cut off the current at once by means of the main switch. The starting current may be as much as 50 per cent. above the working current. **Any abnormal current of**

the searchlight ammeter is usually traceable to either a mushroom on the negative carbon or careless handling of the hand feed. If the lamp does not feed properly, it is because there has been a burn-out or that the lamp itself is not clean; in the great majority of cases dirt is the cause. The key to good searchlight operation is thorough cleanliness in all the parts and frequent opportunity for practice by those not ordinarily called upon. The mirrors will spot or frost in time, and this action is much hastened on board ship by the practice of exposing them to the rays of the sun while drying out the barrel. The action of direct sunlight will quickly ruin the silvered surface of a mirror. Every projector front should be fitted with an extra outside door to protect the glass front. Sometimes it is desired to use a beam of light that will spread out, and in such cases it is customary to fit the front with **diverging lenses** that are plano-convex strips instead of the plain flat strips ordinarily used.

ELECTRIC LIGHTING.

(PART 4.)

TESTING ARC-LIGHT LINES.

1. Since street arc-lighting circuits are generally long, considerably exposed, and of comparatively small wire, they always give more or less trouble on account of grounds, breaks, and crosses. Breaks are of quite frequent occurrence, especially during heavy wind or sleet storms, and very often cannot be detected by a mere inspection of the line. The wire may be broken while the insulation holds the ends together, so that, to all appearances, the line is intact. Breaks are especially liable to occur at the point where the line loops from the pole to the lamps.

Grounds are most likely to occur around the fronts of stores where the wires are run in proximity to iron awnings or fittings. Also, where the lines run through trees, there will always be more or less of a ground, especially in wet weather. In this case, however, the trouble would be more correctly termed a leak, as it is due to defective insulation and does not constitute a direct connection to ground, as would happen, for example, if one of the lines came into contact with an iron pole or a gas or water pipe.

Crosses are caused by one line coming into contact with another, and, under ordinary conditions, should not occur frequently if the line is well constructed. Of course, heavy storms, especially sleet storms, may cause a great deal of trouble on arc lines, but we are now speaking of the troubles that are liable to occur under ordinary working conditions.

All arc lines should be tested at intervals during the day to see if any faults have developed, so that they may be looked up and remedied, if possible, before it comes time to start up in the evening. There are various methods of testing for grounds and breaks, but in the great majority of cases they are located by the use of an ordinary magneto-bell. Such a bell is very convenient for testing purposes, as it requires no battery for its operation and is able to ring through a long length of line; moreover, it is easily carried around from place to place. Another testing instrument that will be found very useful around an arc station is a portable Wheatstone bridge. These are now made in a variety of forms that are compact and convenient to work with. They are often very useful in locating faults on lines, but more particularly for making measurements of resistance on dynamo armatures and fields, arc-lamp spools, etc.

2. Locating Breaks.—Series arc circuits should be frequently tested for breaks by connecting a magneto to the terminals of the circuit, at the station, and ringing it up. If the bell fails to ring, it shows that the circuit is broken somewhere and the break should be looked up at once. If

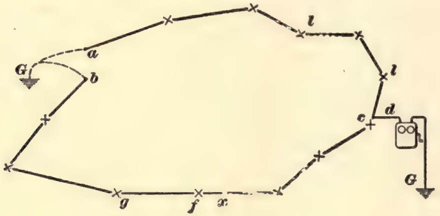


FIG. 1.

the circuit is aranged in loops that may be cut out by means of switches on the poles, the first thing to do is to cut out the loops in succession until a ring is obtained. This will show in which loop the break is, and the fault may then be further located, as described later; or, in many cases, it

may be found by a simple inspection. In general, however, the problem will be to locate a break on a simple series circuit, such as that shown in Fig. 1. The irregular outline here represents the circuit, or portion of a circuit, of which *a*, *b* are the terminals; *l*, *l*, etc. represent the lamps. It is found by ringing up between *a*, *b* that there is a break on the circuit. We will indicate this break at the point *x*, though its location is not known as yet. The first thing to do is to connect *a* and *b* together and ground them, as shown by the dotted lines. The lineman then goes out to the point *c*, as near the middle of the circuit as possible, and opens the circuit by lowering a lamp and removing the wires or in any other way that may be convenient. He then attaches one terminal of the testing magneto to ground, by connecting it with a hydrant or other ground connection that may be at hand, and the other terminal to one end of the circuit *d*. He then rings up, and if the bell rings, it shows that the portion of the circuit from *d* around to the station is all right and that the break is in the other half. He then closes the circuit at *c* and moves on to a place *f*, about half way between *c* and the station. The circuit is here opened and the magneto-bell connected as before. If a ring is obtained when the bell is connected to the left-hand end of the line, it shows that the stretch of circuit *f–g–b* is intact; while, if the bell does not ring when connected to the right-hand side, it shows that the break is between *f* and *c*, because the previous test showed that the part *d–l–l–a* was all right. In this way, by making a few tests, the lineman can locate the stretch of circuit in which the break occurs between narrow limits, and the break itself can then usually be located by a careful inspection.

3. Locating Grounds.—When a line becomes grounded at any point *x*, as indicated in Fig. 2, the ground may be located by using a magneto, in which case the ends of the line *a*, *b* at the station are left open, instead of being grounded, as when testing for breaks. The line is then

opened about the middle point *c* and each side rung up, one terminal of the magneto being connected to the ground. It is evident that the side on which a ring is obtained is

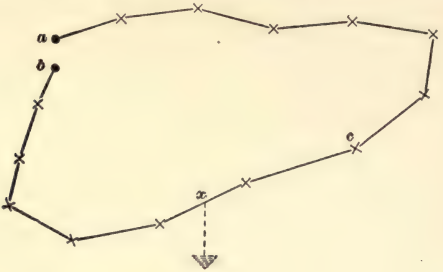


FIG. 2.

the one on which the ground exists. The half on which the ground is located is then opened at its middle point, and, in this way, the part of the line that is grounded is soon located within narrow limits.

4. Locating Grounds by Means of Voltmeter. — If a high-reading voltmeter is available, it may be used for locating grounds on an arc circuit, as indicated in Fig. 3.

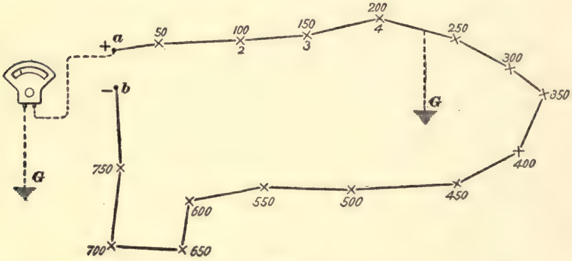


FIG. 3.

The dynamo is here omitted, but it is supposed to be operating the circuit connected to its terminals *a*, *b*.

In this case we have, say, 15 lamps operated on a circuit.

The total pressure generated by the dynamo will then be about $15 \times 50 = 750$ volts, allowing 50 volts per lamp. The difference of potential between the negative side of lamp *1* and $a+$ will be 50 volts, between the negative side of *2* and $a+$ 100 volts, and so on, as shown in the figure. If we connect one terminal of the voltmeter to $a+$ and the other to ground, we will get a reading whenever there is a ground on the line. Suppose, for example, that there is a ground at G. We will then have the voltmeter connected across four lamps and it will give a reading of about 200 volts. The voltmeter reading, therefore, indicates how far the ground is out on the line. If, for example, we obtained a reading of about 100 volts, we will know that the ground is somewhere between the second and third lamps.

5. Differential Method of Locating Grounds.—This method consists in balancing the drop through an artificial line against the drop through the portion of the circuit from the station to the point where the ground exists. The method will be understood by referring to Fig. 4.

The terminals of the circuit are indicated at a, b, and, for the sake of illustration, we have shown 10 lamps. The total pressure generated by the dynamo will be about 500 volts, and the drop in pressure between $a+$ and different points on the circuit will increase as the lamps are passed, as shown by the numbers *50*, *100*, etc. The testing apparatus consists of a number of *equal* resistances *1*, *2*, *3*, *4*, etc. connected in series with terminals brought out to a switch, as indicated. These resistances should be fairly high, say about 50 ohms each. Ordinary 52-volt incandescent lamps will answer. A detector galvanometer C is connected to the switch blade and to the ground. Any instrument that is reasonably sensitive will do, as it is not necessary for it to read either volts or amperes. This device should have as many resistances as the greatest number of lamps on any circuit that is likely to be tested. One end x of the resistance is connected to $a+$. The other end of the circuit $-b$ is connected at the point z, so that the number of

resistances will correspond to the number of lamps on the circuit to be tested. The switch arm is then moved over to the right until the galvanometer deflection comes to zero. In this case, the deflection will become zero when the arm is at the point *y* between resistances *6* and *7*. It is evident that the fall of pressure from *a*+ through the artificial circuit corresponds to the fall in pressure from *a*+ around

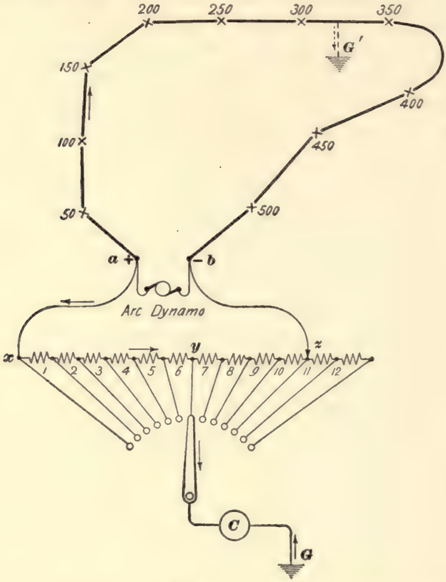


FIG. 4.

the arc line; hence, when a point is reached when the drop in pressure from *a*+ around to the ground is equal to the drop in the artificial line, the two pressures counterbalance each other, as indicated by the arrows, and no current flows through the galvanometer. As soon as the point corresponding to that where the ground exists is passed on the switch, the galvanometer will reverse its deflection.

LIGHTNING PROTECTION FOR ARC CIRCUITS.

6. Series arc-light circuits are very apt to bring in lightning discharges to a station, because they cover such large areas and are usually pretty well exposed. They should, therefore, be well protected by lightning arresters. The arresters used on arc circuits differ little, if any, from those used on other circuits. Care must, of course, be taken in selecting an arrester to see that it is adapted to the voltage of the circuit. Many of the older types, which were quite satisfactory on circuits operating as high as 60 to 75 lamps, are not suitable for high-voltage circuits operating 125 to 150 lamps. If the older types of arrester are to be operated on such circuits, two of them should be connected in series.

7. Thomson Arrester.—Fig. 5 shows the Thomson magnetic blow-out arrester that has probably been used in the past more extensively on arc circuits than any other one type. It is similar in principle to the blow-out arrester used on constant-potential circuits, except that the coils are in series with the dynamo instead of being connected across an auxiliary air gap. The coils, therefore, carry the

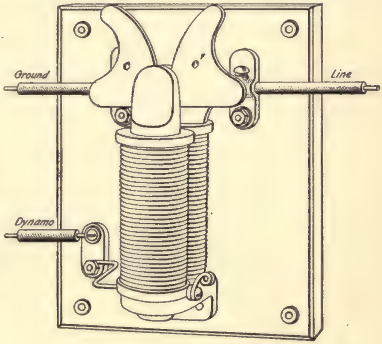


FIG. 5.

current all the time the dynamo is in operation. There is little objection to this in the case of an arc circuit where the current is small. For constant-potential circuits it would be inconvenient to carry the main current through the

blow-out coils, and unless they were of very low resistance there would be considerable loss of energy. The air gap is between the vanes c, c'. Fig. 6 shows how the arresters are connected. Current from the dynamo D flows through the coils A and out on the line, thus setting up a magnetic field between

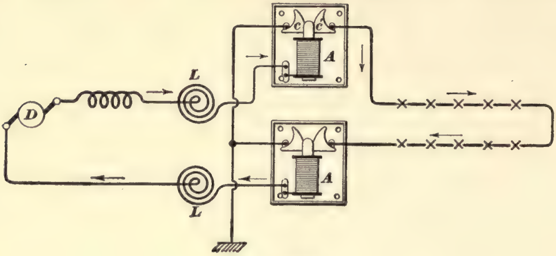


FIG. 6.

the pole pieces. When a discharge comes in over the line, it jumps from c' to c and passes off to the ground. The coils A, A act as choke, or reactance, coils to keep the discharge out of the dynamo, but sometimes additional choke coils are inserted, as shown at L, L, in order to make the

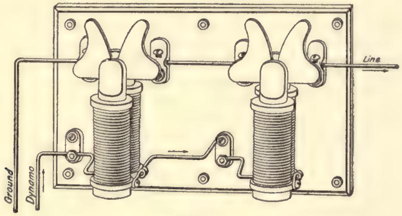


FIG. 7.

protection still more sure. This same style of arrester is mounted in a weather-proof box for use out on the line; the one shown in Fig. 5 is intended for use in the station. Fig. 7 shows two of these arresters connected in series for circuits on which more than 75 lights are operated.

8. The type of blow-out arrester described in *Electric Lighting*, Part 2, and made by the General Electric Company for use on direct-current lighting and power circuits, is now also used on arc-light circuits. This arrester has a smaller air gap than those just described and, hence, affords a better protection especially against static charges that gradually accumulate on the lines and do not take the form of a regular lightning discharge. Moreover, as the working parts of this arrester are mounted in a porcelain case, there is much less liability of dust and dirt becoming lodged in the air gap.

9. The arresters just described are, of course, intended for use with direct current. For alternating-current systems, the arresters described in *Electric Lighting*, Part 2, in connection with alternating-current incandescent circuits may be used.

10. Lightning Arrester for Arc Lamps.—Although lightning may not get into the station, it sometimes punctures the insulation of the lamps out on the line and is responsible for many burned-out coils. In order to prevent this, small arresters, or, rather, simply spark gaps, may be connected across the terminals of the lamp. Fig. 8 shows a simple arrester for this kind of work. This consists simply of two brass cylinders with a small gap between them. When a discharge comes along the line, it will jump between the cylinders and thus pass along to the regular lightning arresters, which will

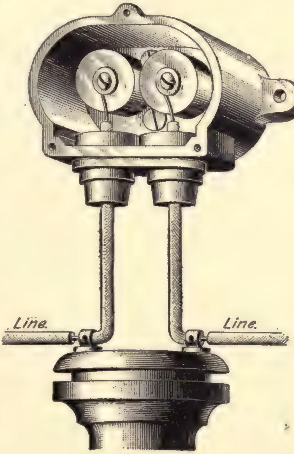


FIG. 8.

carry it to ground. The lightning will jump the gap in preference to passing through the lamp on account of the self-induction and consequent reactance of the regulating coils in the lamp.

11. It will generally pay to have a number of arresters, connected between the line and the ground, distributed over the line instead of depending on the station arresters alone for protection. All arresters should be provided with a good ground connection, otherwise they will be of little value.

STATION EQUIPMENT.

12. General Remarks.—Having considered the lamps themselves and the line used to convey the current to the lamps, next in order comes the apparatus for the generation and control of the current supplied to the various arc circuits. This means a consideration of arc-light dynamos, switchboards, and methods of operating arc lights by alternating current. Attention has already been called to the fact that large numbers of arc lamps are run on constant-potential circuits. These lamps are operated by the same machines and from the same mains used for the incandescent lighting, so that the equipment described in *Electric Lighting*, Part 1, is suitable whether the lamps be direct or alternating. We will, therefore, confine our attention to the special equipment necessary for operating constant-current series circuits.

13. Lamps may be operated in series by means of a constant current, either direct or alternating. In case direct current is used, it is supplied by regular arc-light dynamos. In case alternating current is used, it is generally supplied from a constant-potential alternating-current dynamo supplying the lamps through a regulator or transformer of some kind that will serve to keep the current at the correct value,

no matter how many lamps there may be in the circuit. Constant-current alternators have not as yet been used to any great extent, but as the use of series alternating arc lamps extends, it is quite probable that they may be used more than has been customary in the past.

CONSTANT-CURRENT ARC-LIGHT DYNAMOS.

14. The constant-current arc-light dynamo may in many ways be considered as a decided contrast to the constant-potential direct-current machines used for low-pressure lighting or street-railway work. In the first place, arc machines must generate a comparatively small current (from 6 to 10 amperes), but the maximum pressure that they are called upon to deliver at full load is very high. Moreover, they must be constructed so as to keep the current at the required amount through a wide range in the number of lamps operated.

The constant-potential dynamo does just the opposite. It maintains the pressure (usually from 110 to 600 volts) at a constant or nearly constant value and the current varies with the load. A constant-potential machine can be made self-regulating by providing it with a compound field winding. In order, however, to make a direct-current machine regulate for constant current, it is necessary to provide it with an electromechanical regulator of some kind that will adjust the voltage with changes in load, so as to keep the current constant.

These regulators are always more or less complicated. It is quite a common thing to go into arc-light stations and find the regulators thrown out of action. Some of them give so much trouble that the station men prefer to regulate the machines by hand rather than bother with them. Most of these regulators shift the brushes, and if the load does not change suddenly (as, for example, on a street-lighting circuit), the dynamo tender can regulate the current by

watching the ammeter and regulating the position of the brushes by hand when necessary. On the other hand, many constant-current arc machines regulate almost perfectly and give very little trouble if the machine is only kept clean and in good condition.

15. For convenience, constant-current arc machines may be divided into two general classes: (*a*) those with open-coil armatures and (*b*) those with closed-coil armatures. The Brush and Thomson-Houston machines belong to the first class, and the Fort Wayne or Wood, Excelsior, Western Electric, and Ball belong to the second class.

OPEN-COIL MACHINES.

16. The Thomson-Houston (T. H.) Dynamo.—This machine has been very largely used for arc lighting and has given excellent service, notwithstanding the fact that its regulating mechanism is rather complicated and that, as a whole, it has more peculiarities than almost any other direct-current machine in common use. The General Electric Company, who succeeded the Thomson-Houston Company, do not now manufacture this type as their standard arc machine; but since large numbers of T. H. machines are in use, we will consider a few points regarding them.

Fig. 9 shows the general appearance of this arc machine, and Fig. 10 shows how it is connected with the wall controller and the lamp circuit. The arrangement of the plug switchboard, which is merely shown at *A*, Fig. 10, in order to make the diagram complete, will be fully explained later. *B*, Fig. 10, is the wall controller that is used to throw the regulating magnet *M*, Fig. 9, into or out of action whenever a movement of the brushes is necessary to keep the current constant. *R* is an adjustable rheostat connected in shunt with the right-hand field coil. Constant-current arc machines are always series-wound, i. e., the field coils are

connected directly in series with the armature. If a shunt is connected across one of the field coils, as in this case, the current through that coil is reduced and the field is correspondingly weakened. This rheostat is used to improve the regulation of the machine when it is operated on a number of lamps considerably less than its normal capacity. The

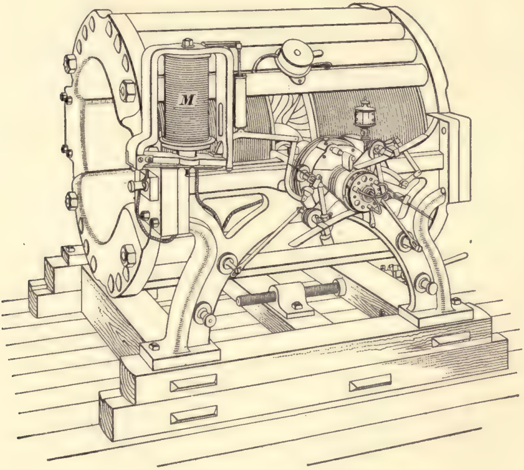


FIG. 9.

machines are, however, frequently operated without any rheostat, especially if they are worked at nearly full load. W is a recording wattmeter used to measure the total work done by the machine. The current coil of this wattmeter is connected in series with the dynamo and lamps, and the pressure coil is connected across the terminals of the dynamo in series with the resistance r.

17. Armatures for T. H. Dynamos.—The old style T. H. armature was nearly spherical in shape, but it was

essentially of the drum type, because the wire was wholly on the outer surface of the core and the coils overlapped. The objections to it were that it was difficult to wind, difficult

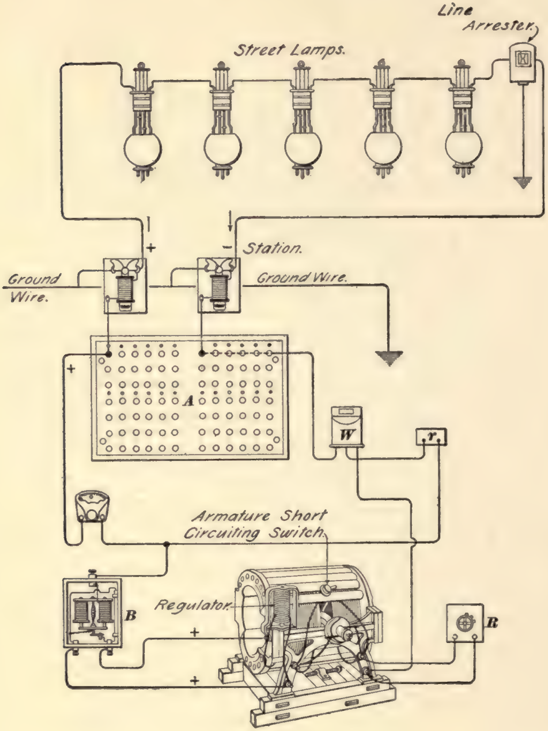


FIG. 10.

to repair, and poorly ventilated. The later types of T. H. machines are, for these reasons, equipped with the ring-type armatures.

Fig. 11 indicates the construction of this later type of armature. In this figure, the spider that supports the core has been removed, and only a portion of the coils is shown in place, in order to indicate the method of construction. The core *A* is built up of sheet iron and has a slot *S* in it wide enough to admit the coils *c*, so that they may be removed if necessary. A laminated iron piece *b*, fitting into slot *S*, is held in position by end pieces and locks the core securely. The coils *c* are wound on forms and are heavily insulated. The core is supported by the radial arms of the armature spider which fit into grooves. This style of armature gives much better ventilation than the older type and is very much easier to repair in case a coil burns out.

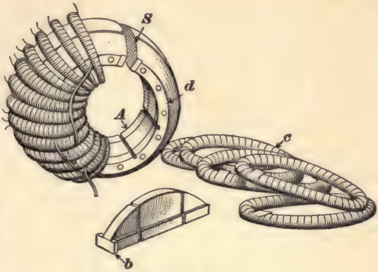


FIG. 11.

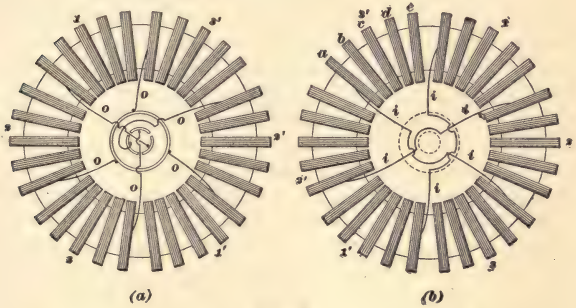


FIG. 12.

18. The connections for the ring armature are the same in principle as those of the drum. The coils are divided into three groups and one end of each group is connected

to a common junction. The remaining three ends are then carried to the commutator segments. Fig. 12 (*a*) and (*b*) shows the connections of a T. H. ring armature, (*a*) being the connections as seen from the commutator end and (*b*) from the pulley end. The individual coils of each group, such as *a*, *b*, *c*, *d*, *e*, etc., are connected in series. The ends marked *i* are inside ends of coils; those marked *o* are outside ends. Outside of the change in the style of armature and some improvements in the bearings, the T. H. machine has been changed but little since it was first brought out.

19. General Remarks on T. H. Machines.—In operating the T. H. machine, care must be taken to see that the brushes are correctly set, with regard to the commutator, and also that the commutator is properly set on the shaft, with regard to the armature. Instructions for doing this are furnished by the manufacturers and a gauge is provided for setting the brushes. Failure to attend to these points will result in "flashing," or the machine may refuse to pick up its load at all.

20. Flashing is a fault to which arc-light dynamos are especially subject. It consists in a momentary short-circuiting of the machine by an arc jumping around the commutator from brush to brush. This produces a flash, so well known in connection with these machines. It may arise from a number of different causes. In the T. H. machine, an improper setting of the brushes or commutator referred to above may cause it, also defects in the air blast. If the jets become stopped up or if the blower itself is out of order, the puffs of air will not be delivered so as to blow out the spark. This will allow it to carry over to the adjacent segment and a flash will result. A flash is immediately followed by a lowering of the regulator and must not be confounded with the ordinary sparking of the machine. When a T. H. machine is running under normal conditions, there is a spark about $\frac{3}{16}$ to $\frac{1}{4}$ inch long at the ends of the brushes. This spark has a violet tinge and does no special harm; in fact, an experienced hand can tell by the size and color of

the spark if he has the brushes and commutator adjusted correctly or not. When flashing occurs, it generally indicates that something is wrong, and the trouble should be looked up and remedied. Bad contacts in the wall controller are another cause of flashing; an overload on the dynamo or a low speed will also give rise to it. Sometimes flashing is caused by a short circuit or open circuit in one of the armature coils. Trouble of this kind in the armature will, as a rule, not only cause bad flashing, but will also cause the brushes to spark much more than usual. Sometimes flashing occurs when there is no fault in either the wall controller or the dynamo. The wires may be crossed at some point on the line, so that as they sway back and forth, part of the circuit is cut in or out, thus throwing part of the load on and off. With some styles of differential lamps a break in the shunt circuit of one or more of the lamps will often cause flashing. Such a break may be caused by lightning and will prevent the lamp feeding when it should. The characteristic of flashing resulting from this cause is that it occurs at regular intervals. As the carbons of the faulty lamp burn away they become farther and farther apart, because the shunt coil is out of action and cannot make the lamp feed. The resistance of the arc finally becomes so great that the dynamo can no longer keep the current constant and the machine finally flashes. This momentarily cuts off the current from the circuit, so that the carbons drop together and the same performance is repeated.

21. Sparking. — As already stated, T. H. machines always run with a spark, even when they are in perfect condition. Sometimes, however, they spark more than they should, and in such cases the trouble should be looked up. Inaccurate setting of the brushes, loose brushes, or loose commutator segments will cause sparking. Defects in the air jets, dirty commutator, too much oil on commutator, and ragged or bent brushes are other causes. Sparking is sometimes caused by the dynamo generating a larger current than it should If this is the case, it

will be indicated by the ammeter, and the wall controller should be inspected and adjusted. On account of the peculiar construction of the T. H. machine, there are a great many things that may give rise to flashing and sparking. Those given above are a few of the more important ones. It must not be inferred, however, that the machine is not satisfactory on this account. In fact, there are few arc dynamos that have given such generally good service as the T. H., and after a man has worked around them a while he soon becomes accustomed to the method of handling them and has very little trouble. The wall controllers require scarcely any attention and will work year in and year out without giving trouble. The T. H. machine has been replaced by other types, not because it was unsatisfactory, but because of the demand for larger machines of higher efficiency which could handle a larger number of lamps. Most of the older styles of constant-current arc dynamos had a very low electrical efficiency compared with constant-potential dynamos of the same output.

22. The Brush Arc Dynamo.—The old style Brush arc machine was very simple in construction. Large numbers of these machines are still in use, but they are gradually being replaced in the larger plants by the later style shown in Fig. 13. These machines are much larger than the bipolar type and have a higher efficiency. The armature M is of the ring, open-circuit type, and its general construction is the same as that of the older style armature with a number of improvements in the mechanical details and method of insulation. The connections are also slightly different in order to adapt the armature to a four-pole field. Instead of connecting diametrically opposite coils in series, as in a two-pole machine, four coils situated one-quarter of a circumference from one another are connected in series and the terminals brought out to the commutator segments.

The field is the same in some respects as that on the old machine, but there are four poles on each side of the armature instead of two. On each side the poles are alternately

north and south, but poles directly opposite each other are of the same polarity. For example, in Fig. 13, poles A, A are alike and of one polarity, while B, B are also alike but of opposite polarity to A, A. In placing and connecting

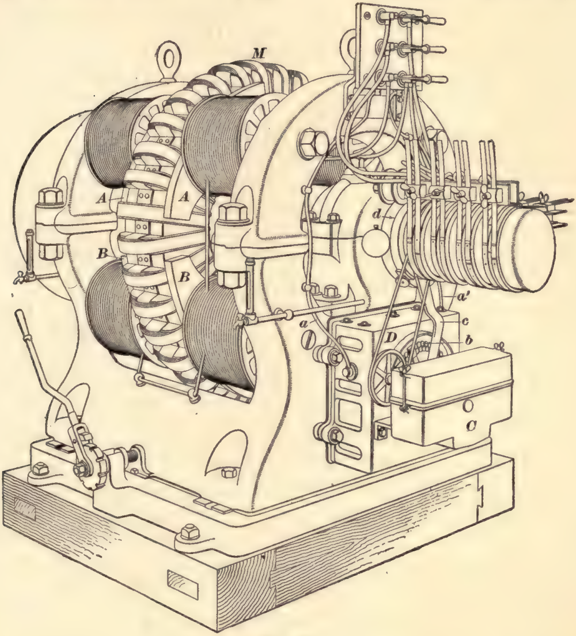


FIG. 13.

the field coils, the instructions sent out by the makers should be followed carefully, and it is always a good plan to send current through the coils and test the polarity with a compass before starting up the machine.

23. The other chief point of difference between the new-style and old-style Brush machine lies in the regulator. The old regulator was entirely separate from the dynamo

and took the form of a carbon resistance connected in shunt across the terminals of the field. This resistance was made of a pile of carbon plates that were pressed together by a lever pulled by a magnet connected in series in the circuit. If the current increased, the magnet pulled on the lever and pressed the plates together, thereby lowering the resistance in shunt with the field. This allowed a greater proportion of the current to flow past the field windings, thus cutting down their magnetizing power, lowering the voltage, and bringing the main current back to its proper value. If any regulation of the brushes were necessary to prevent undue sparking, it was accomplished by hand. In the later machines the regulator is mounted on the dynamo and not only varies the amount of the resistance shunted across the field, but also tips the brushes so as to regulate the sparking.

24. The regulator, Fig. 13, is in the box *C* and will be described in detail later. The rheostat *D* is connected in shunt across the terminals of the field by means of the wires *a*, *a'*. This resistance is divided into a number of steps, connections to which are made by an arm moving over the contacts *b*. This arm is moved by the regulator and at the same time the brushes are tipped by means of the rocker-arm *c* attached to the brush-holder yoke *d*.

25. The Regulator.—Two types of regulator have been brought out for the multipolar Brush machines. The first type used magnetic clutches to move the rheostat arm. A shaft on which were mounted two magnetic clutches was driven at a uniform speed by a belt from the main shaft. The shaft carrying the rheostat arm was moved by the clutch shaft by means of beveled gears, so that when current was allowed to pass through one clutch, the rheostat arm was moved in one direction, and when the other clutch was thrown into action, the arm was moved in the opposite direction. The current through the clutches was regulated by a wall controller. This controller consisted of two series

magnets provided with armatures carrying contacts, so that when the current became low one clutch was energized, and when too large, the other. This form of regulator is not

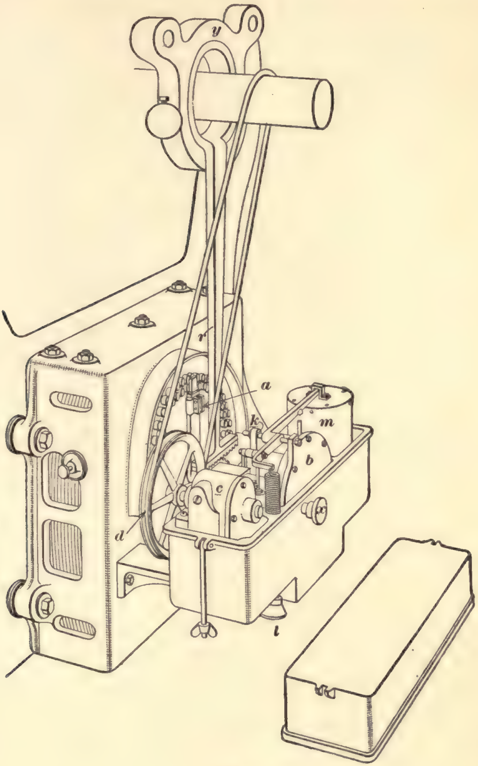


FIG. 14.

now manufactured, so that it will not be necessary to describe it in detail. The one now made is shown in Fig. 14. This regulator is shown at *C*, Fig. 13, but Fig. 14 is a larger

view, showing the regulator with its rheostat detached from the machine. It requires no wall controller and is operated by an encased magnet *m* connected in series with the lamps. The magnet *m* does not move the rheostat arm *a*, but simply controls a valve that admits oil under pressure to either side of a vane or piston that swings around in the closed chamber *b*. The oil pressure necessary to operate the piston is maintained by means of a small rotary pump *c*

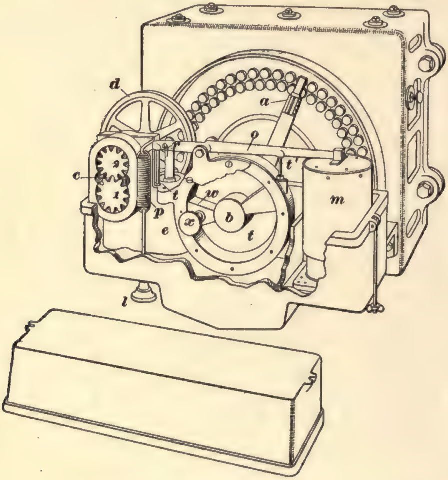


FIG. 15.

driven by a belt from the dynamo shaft running on pulley *d*. The lower case is filled with oil to a point a little below the rheostat-arm shaft.

Fig. 15 shows the working parts of the regulator with the outer casing removed. The pump consists of two gears *1*, *2*, Fig. 15, meshing with each other. Oil is drawn from the lower part of the box and discharged through the valve, which moves up and down in a chamber at *e*. The series magnet *m* pulls on the lever *o*, which operates against

the adjusting spring *p*. The valve is operated by means of the link *r*. The piston or vane *b* is movable and is free to swing around in the chamber *t*. The partition *w* is fixed, so that when oil is pumped in above *w* and is allowed to flow out below, the vane *b* moves clockwise and moves the rheostat arm in the same direction. When oil is pumped in on the lower side and allowed to flow out on the upper, the vane moves counter clockwise. When the current is at its normal value, the valve is in its central position and the ports

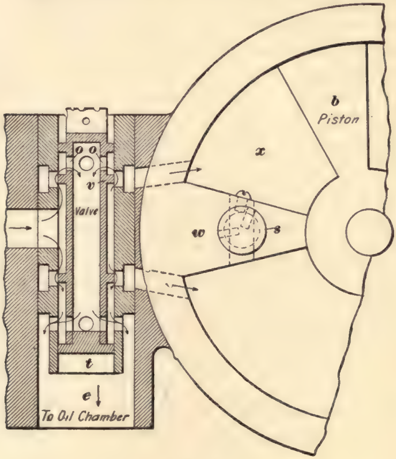


FIG. 16.

are arranged so that the oil passes in and out of the valve chamber without affecting the piston. Under such circumstances, therefore, the rheostat arm remains stationary.

Fig. 16 shows the arrangement of the valve. It is here shown in its mid-position and the arrows show how the oil flows past the valve and back into the chamber. When the valve is raised slightly, the flow through the ports *o*, *q* is stopped and oil is forced into the chamber *x*, thus forcing the piston to the right, or clockwise. As soon as

the current has regained the normal amount, the valve again assumes the central position and the oil flows through it as before. If the current falls below normal, the magnet becomes weakened and the valve moves below the central position. In this case the upper chamber x is cut off from the pump, but is opened to the outside while the corresponding lower chamber is opened to the pump and cut off from the outside and the vane or piston b is forced to the left, or counter clockwise. The valve s is used to make an opening between the two chambers, so that the action of the regulator may be stopped when desired. Any adjustment that may be found necessary is made by varying the tension on spring p, Fig. 15, by means of the knob l at the bottom of the case. The quickness of action can also be regulated by varying the length of the stops t, t' on the lever o, Fig. 15.

26. In addition to moving the rheostat, the regulator also tips the brushes by means of an arm extending down from the rocker and carrying a toothed arc that engages with a small spur wheel on the shaft carrying the rheostat arm. By this movement the brushes are adjusted with the changes in load so as to keep the spark at the brushes about $\frac{3}{8}$ inch long on short circuits and $\frac{1}{8}$ inch long on full loads.

Some of these machines are provided with what is called a **spark-controlling switch.** This is an adjustable resistance in series with the rheostat. By varying this resistance, the field strength of the machine may be adjusted, to a certain extent, independently of the position of the rheostat arm, and the field strength determines, to a large extent, the amount of sparking. On these machines the spark at the negative brush (the top or horizontal brush) follows the brush in a zigzag line, while that on the positive, or vertical, brush follows the brush in a straight line.

27. The controller described above will hold the current at its correct value with very little variation either way.

Its chief advantages over the magnetic clutch controller are that it requires no wall controller and it is not so liable to give a seesawing effect. The regulation is brought about more evenly than when clutches are used and is not so liable to overshoot the mark and then have to be brought back again, thus giving rise to surging effects in the current. The oil regulator is comparatively simple in construction, and there are few parts of it that are liable to give trouble, and the moving parts run in oil, so that the wear is very slight. A light dynamo oil should be used, and when the machine is first installed the old oil should be drawn off and replaced by new at least once a week until all grit and dirt have been cleaned out. The cover must never be left off the regulator.

28. Connections of Multipolar Brush Arc Dynamo. The number of coils on the armature and the number of commutators depends on the size of the machine. The larger sizes have four commutators and the smaller three. Each group of coils, with its commutator and brushes, may be considered as a dynamo by itself, because the various sets of windings have no connection with one another unless they are connected through the outside circuit. On account of having this style of armature winding with a number of separate commutators, the machines may easily be connected so as to operate a single circuit or a number of circuits, as previously explained.

CLOSED-COIL MACHINES.

29. The Wood Arc Dynamo.—This machine has a simple closed-coil ring armature and a commutator divided into a large number of segments so as to make the voltage between segments low and prevent undue sparking. Fig. 17 shows one of these machines of 125 lights capacity, and, therefore, capable of generating about 6,250 volts at full load. The controlling magnet *m* of the regulator here

shown is connected in series with the line and operates the lever *n*. The brushes are moved by means of a small double friction clutch that is contained in the casing shown at *a*. When the lever is pulled up beyond the normal position, the clutch moves the brushes forwards by means of the gears *b*, *e*, *d*, thus lowering the current. If the current becomes too weak, the lever moves down and the clutch moves the

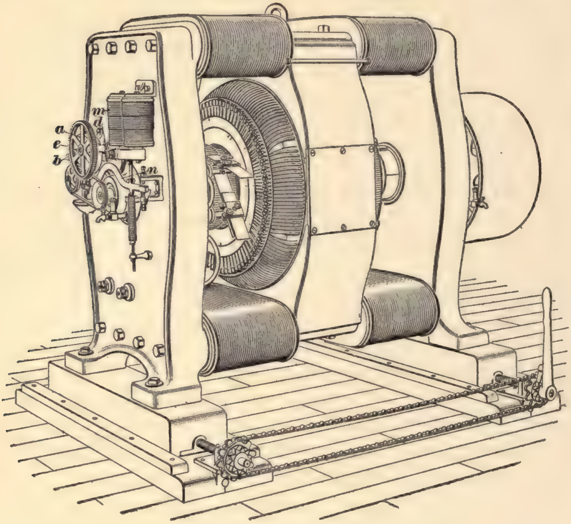


FIG. 17.

brushes back, thus increasing the current. These machines operate on a single circuit and are made as large as 150 lights capacity. The largest size of machine is of a somewhat different design from that shown in Fig. 17, but the principle of operation is the same. The connections used with the Wood system are very simple. The armature, fields, and regulating magnet are all connected in series, and the regulation is effected altogether by tipping the

brushes, there being no rheostat of any kind in shunt with the fields.

30. The **Excelsior** and **Western Electric** machines also have closed-coil armatures. The larger sizes of the more recent Western Electric machines are of the four-pole type and have two pairs of brushes. This dynamo is provided with two regulators and supplies two circuits in parallel. Each of the regulators controls one pair of brushes. This is a somewhat different multiple-circuit arrangement from that of the Brush machine, because there the two loops or circuits are in series and the current is bound to be the same in each, hence only one regulator is needed. Moreover, if the circuit is opened at any point, the full pressure of the dynamo is obtained at the break. When the circuits are in parallel, it is evident that each circuit must have a regulator of its own, but under no circumstances can the pressure obtained exceed that which is ordinarily applied to one circuit, i. e., half the pressure that the machine would have to generate if all the lamps were connected in series.

31. General Remarks.—From the above it will be noticed that the general tendency has been to produce arc machines of larger output rather than to make any radical change in the design. The most modern Brush machines are almost exactly the same, so far as general principles are concerned, as those first manufactured. When it comes to making large constant-current machines, however, difficulties are met with on account of the high voltage that they must generate, and the largest size of Brush machine is only of about 76 kilowatts capacity. This machine generates 9.6 amperes at 8,000 volts or 6.6 amperes at 11,000 volts, depending on the winding with which it is provided. These machines, while small compared with most constant-potential dynamos, are considerably larger than the older types of arc machines and have a somewhat higher efficiency. Large machines are almost a necessity in city stations where a large number of lamps must be operated and where floor space is limited.

CARE OF ARC MACHINES.

32. The ordinary constant-potential dynamo, generating current at 110, 220, or 500 volts, will give comparatively little trouble if it is kept clean and the commutator attended to. Carbon brushes will wear for a long time without requiring much attention. On the other hand, arc machines require considerable attention. It is not the intention here to take up the points relating to particular types of machines, but simply to take up a few points applying to arc machines in general. Instructions relating to particular makes of machines are furnished by the manufacturers.

33. Insulation of Machine.—The insulation between an arc machine and the ground should be high and the mounting should be carried out with this end in view. The dynamo should be fastened to a heavy frame, made of well-seasoned wood, oiled and varnished. The foundation bolts should be so countersunk in this frame that there will be no danger of the base of the machine or its holding-down bolts coming into contact with the foundation bolts. The arc lines connected to the machines are always more or less grounded, and a ground on the dynamo frame will help to bring about a breakdown, besides being dangerous. Sometimes static charges, caused by the driving belt, will accumulate on arc machines where the insulation from the ground is very high. These charges may sometimes be seen jumping from the pole pieces to the armature coils and thence to ground. In order to lead off such charges, a very high resistance may be connected from the frame to the ground. Resistances made of graphite are often used for this purpose, but in most cases a small charred groove from the base of the machine to a foundation bolt will answer. A heavy rubber mat should be provided at each arc machine for the attendant to stand on. One cannot be too careful when working around such high-pressure machines and it is best not to take any chances.

34. Cleaning and Wiping.—In the first place, the fact must never be lost sight of that series arc dynamos generate a very high pressure, much higher, in fact, than many of the alternators in common use. Cleanliness is essential with all dynamo-electric machinery, but it is especially important in the case of arc machines. All dust and dirt must be kept off them or a short circuit of some kind is bound to occur sooner or later. It will pay any station that operates many of these machines to put in a small air compressor and pipe compressed air around the station, so that the dust and dirt may be blown out. Holes and corners can be reached in this way that would never be touched or that could not be reached otherwise. Although a dynamo may look clean to outside appearances, dirt and copper dust will often accumulate in just those places where it will eventually cause a breakdown and from which it would be dislodged if a stiff air blast were used. The commutator of an arc machine always requires more or less sandpapering, and the copper dust resulting from this is especially liable to give trouble. Wherever terminals are carried through castings by means of bushings, as, for example, on the legs of the T. H. dynamo or where brush-holder studs pass through the rocker-arm, care should be taken to see that the insulating washers are kept clean. It is a good plan to clean them with benzine occasionally and to give them a coat of clean, thick shellac. Machines should, if possible, be wiped and thoroughly cleaned immediately after they are shut down. When the machines are warm, the cleaning is much more effective than after they have cooled down.

35. Brushes and Commutator.—Arc machines always spark more or less. This is especially true of the open-coil machines, i. e., the Brush and T. H. This sparking does not cause as much burning of the commutator and brushes as might at first be expected, because the volume of current is small and the heating and burning effects are also small. If the same amount of sparking occurred on a constant-potential

machine delivering a large current, the commutator and brushes would very soon become burned. At the same time, the segments always roughen up to some extent and the commutator should be cleaned. On the T. H. and Brush machines a strip of very fine sandpaper (never emery or crocus cloth) held against the commutator for a minute or two just before the machine is shut down should be sufficient to keep the segments smooth, unless they have been allowed to get in very bad shape. This may be done without removing the brushes, but all copper dust should be thoroughly cleaned or blown out afterwards. It is often a good plan to put a little oil on the commutator, as it generally prevents the cutting of the segments. Oil should, however, be used in very small quantities. If too much is used, it will make the commutator blacken or it may cause flashing. In working around the commutator of these machines, great care should be taken. Use only one hand, and if it is necessary to wipe off the commutator, fasten the cloth on the end of a stick, so that it will not be necessary to bring the hand close to the brush holders.

36. Nearly all arc machines use copper brushes. An exception to this is the Western Electric dynamo, which uses graphite or carbon brushes. The T. H. and Brush machines use thin brushes, consisting of one thickness of rolled copper about .03 inch thick. The brush is divided into a number of fingers by longitudinal slits, in order to make it flexible. Brushes of this kind should rest on the commutator tangentially and should be sprung or bent just enough to give a good, firm contact. Gauges for setting the brushes are generally sent with the machines. The copper brushes used on the Wood, Excelsior, Ball, and other machines having closed-coil armatures are made up of a number of leaves of thin, rolled copper (usually from .01 to .015 inch in thickness). These brushes are set at a slight angle to the commutator, so that the end wears down on a bevel. The sparking always burns the ends of the brushes more or less and draws the temper from the copper for a

short distance back from the tip. This necessitates clipping off the ends from time to time, so as to keep them straight and smooth. After being clipped, the ends should be smoothed up with a fine file. As these brushes are quite thin and do not carry a heavy current, it is not necessary to file the ends to a bevel to suit the commutator, as must be done with the thick copper brushes used on constant-potential machines.

37. Troubles in Armatures. — The troubles in arc armatures are usually of three kinds: *grounds*, *short circuits*, and *open circuits*. Grounds are generally caused by the insulation breaking down between the core and one or more of the coils. As it is not usually possible to get at the insulation between the core and the coil, the only remedy is to rewind the defective part. Short circuits are caused either by two commutator bars becoming connected together, by the coil terminals becoming connected, or by a connection being made between the turns of the coil itself. In any event, a short-circuited coil is almost sure to burn out as soon as the machine is started, because the coil with the short circuit forms a closed circuit in itself, and as soon as it begins to cut lines of force, heavy local currents flow in it. An open circuit in a coil will not, of course, cause the coil to burn out, but it will cause bad sparking at the commutator.

On closed-coil armatures, where the number of coils is large, a defective coil may be cut out temporarily without interfering, to any great extent, with the operation of the machine, but it should be renewed at the first opportunity. A coil may be cut out by disconnecting its terminals from the commutator and putting a short piece of wire or a jumper in its place, as indicated in Fig. 18 (*a*) and (*b*). Here *a* is the defective coil connected to the bars in the usual way,

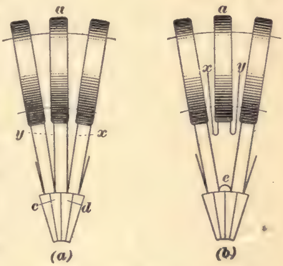


FIG. 18.

as shown in (*a*). This coil may be cut out by disconnecting its ends *x*, *y*, fastening them back out of the way, and connecting bars *c*, *d* by means of a small piece of wire or jumper *e*, as shown in Fig. 18 (*b*). This will usually tide over the difficulty in case of a ground or open circuit in coil *a*. In case the trouble is an open circuit, it is always well to examine the leads coming out to the bars very carefully before cutting out the coil altogether. A large proportion of the breaks met with are in these leads and not in the coil itself, and can be repaired without much difficulty. If any soldering is necessary to repair the break, use a solution of rosin in alcohol for a flux, but do not use soldering acid. Also, turn the armature around so that none of the solder will drop in where it will be likely to give trouble. In case a coil has a short circuit within itself, it will, of course, burn out whether it is disconnected from the other coils or not, and in so doing it is liable to injure adjacent coils. It is best, therefore, to rewind such a coil before attempting to operate the machine.

38. Troubles in Field Coils.—The field coils of arc machines are more liable to become grounded than those of constant-potential dynamos because of the high pressures used. Open-circuited, grounded, or short-circuited field coils may be located by applying the ordinary tests.

Arc machines should be rung up with a magneto for grounds from time to time, and it is best to make a practice of doing it every day. The newer types of machines are very heavily insulated, but as a ground is not only liable to interfere with the operation of the machine, but is also decidedly dangerous, it is best to test out the machines at regular intervals. Sometimes, especially on some of the older machines, the insulation on the inner layers of the field winding becomes gradually carbonized so that the layers become short-circuited. When this happens, the machine will not be able to generate its full voltage and carry its load. A careful measurement of the field resistance with a Wheatstone bridge will usually show whether any

of the layers are short-circuited or not. The correct field resistance is usually given by the makers, so that a defective field coil may be detected.

Grounds on field coils are sometimes caused by lightning getting into the machine and puncturing the spool insulation. In other cases, they may be caused merely by a gradual deterioration of the insulation due to heat or other causes. In rewinding the fields or armatures of arc machines, great care should be taken to see that the insulation on the ends and on the cylindrical part of the spool is as perfect as possible. Carelessness in insulating these spools or armature coils when rewinding often results in a burn-out almost as soon as the machine is started up Fine cambric treated to four or five coats of insulating varnish, mixed with a small amount of linseed oil and allowed to dry, will be found to make an excellent insulating material and is much better than cotton covered with ordinary shellac varnish. The safest plan, however, is to note carefully the way in which the spool was insulated before and then see that it is repaired so as to be at least as good.

39. Reversal of Polarity.—Sometimes the polarity of arc machines becomes reversed. This is usually due either to lightning, wrong plugging at the switchboard, or the circuit from the machine coming into contact with some other circuit. When a machine's polarity is reversed, the lamps operated by it will burn "upside down," i. e., the lower, or short, carbons will be positive and will burn twice as fast as the upper. If the current is allowed to flow in the wrong direction for any great length of time, the bottom carbon holders will be destroyed. It is important, therefore, to see that trouble of this kind is remedied as soon as possible. As far as the lamps are concerned, the trouble can be overcome by simply reversing the plug connections at the switchboard, but the polarity of the dynamo should be righted at the first opportunity. This may be done as follows: Connect the brushes together by a piece of wire so

that the armature will be short-circuited and, hence, will allow current to pass through the fields without running the machine as a motor. On the T. H. machine this can be done by simply closing the armature short-circuiting switch, or field switch, as it is sometimes called. Then connect the positive pole of another machine to the negative pole of the machine to be fixed and allow the current to flow for a few moments. If another machine is not available, a number of cells of battery may be used. This will reverse the polarity and bring the machine back to its former condition. After this is done, the short-circuiting loop may be removed from the brushes. Do not attempt to reverse the polarity while the machine is running.

40. Running Arc Machines in Series. — Sometimes conditions may arise where it is necessary to run two arc machines in series in order to supply the lamps on a given circuit, because the number of lights to be operated may exceed the capacity of any one of the available machines. The two machines are connected in series by connecting the positive terminal of one to the negative terminal of the other, in just the same way as cells of battery are connected together when their E. M. F.'s are to be added. When arc machines are run in this way there is often trouble due to the current seesawing or *hunting*, as it is sometimes called.

The current, instead of remaining steady, surges up and down. This is caused by the unstable action of the regulators on the two machines; both try to do the regulating at once and the result is an unstable condition of affairs. The best thing to do under such circumstances is to throw one regulator out of action and make the machine generate its full-load voltage by blocking the regulator or setting the brushes at their position of maximum E. M. F. This machine will then generate a constant E. M. F., and whatever changes are necessary will be taken care of by the regulator on the other machine.

ALTERNATING-CURRENT ARC-LIGHT DYNAMOS.

41. Constant-Current Alternators. — The operation of arc lights in series from constant-current alternators is not common, although large numbers are operated in parallel from constant-potential machines. There is no particular reason why a constant-current alternator cannot be built, and, in fact, such alternators have been built and used to a limited extent. They have, however, the same disadvantage as direct-current constant-current machines; i. e., in order to operate a large number of lamps they

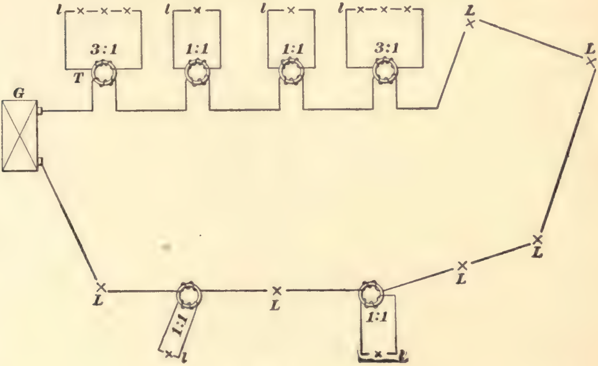


FIG. 19.

must generate a high pressure, and it is not possible to build machines of large output because of the difficulty of insulating them properly. In the few cases where lamps have been operated from constant-current alternators, each lamp was usually supplied through a transformer connected in series with the line, as indicated in Fig. 19. These transformers were usually wound for a ratio of transformation of about 1 to 1 or 2 to 1; i. e., to get a pressure of 50 volts across the lamps, the pressure across each primary would be 50 or 25 volts

and the pressure generated by the alternator would be, approximately, equal to the pressure across each transformer multiplied by the number of transformers connected in the circuit.

This method of operating alternating arc lamps was originally brought out before the enclosed-arc lamp came into use, but was never adopted to any great extent, more on account of the unsatisfactory operation of the alternating-current open-arc lamp than anything else. Now that the alternating-current enclosed-arc lamp has proved a success, it is quite possible that the use of constant-current alternators may become more common. The Westinghouse constant-current alternators are the same in general construction as their constant-potential machines, but are made so that the armature will exert a strong reaction on the field. The armature reaction of these machines is so heavy that any increase in current decreases the field strength to such an extent that the current remains constant. They do not, therefore, require any outside regulating device, or, in other words, they were said to have **inherent regulation.**

42. Although it is quite possible to operate alternating-current arc lamps in series from constant-current alternators, as described above, the present practice is to generate the current by constant-potential alternators and then to supply it to the series circuits either directly, by means of special constant-current transformers, or through a regulator of some kind that will vary the E. M. F. applied to the circuit as the load varies. The advantage of this plan is that it allows series arc lamps to be operated from the same dynamo used to operate incandescent lamps. Also, one large alternator operating at a moderate pressure can be made to operate a large number of series lamps by running a number of circuits all fed in parallel from the same dynamo and each circuit provided with an independent regulator or transformer to keep the current in that circuit constant.

OPERATION OF SERIES ARC LAMPS FROM CONSTANT-POTENTIAL ALTERNATORS.

43. Operation Directly From Machine.—Suppose that we have an alternator *A*, Fig. 20, generating current at a constant pressure of 2,000 volts. If we use enclosed-arc lamps, each lamp will take about 80 volts and we may connect about 25 lamps in series across the line, as indicated. This is similar to the method previously described for operating incandescent street lamps in series. With this scheme of connection it is necessary to provide each lamp with a cut-out of some kind that will insert a resistance or reactance

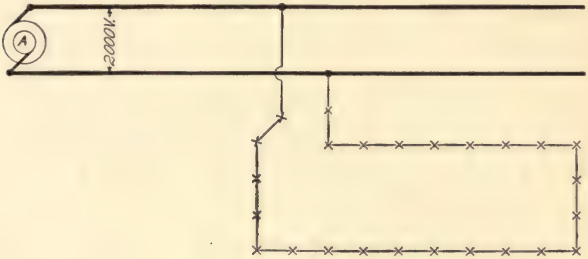


FIG. 20.

in the circuit whenever a lamp is cut out. If this were not done, the current would increase whenever a lamp was cut out, for it must be remembered that the pressure applied to the circuit is constant no matter how many lamps may be in operation. Each lamp is, therefore, provided with a small choke coil that sets up a counter E. M. F. and keeps the current constant. A coil of this kind consumes but little energy, but it introduces a certain amount of self-induction into the circuit and lowers the power factor.

44. Use of Adjustable Transformer.—The operation of lamps direct from the machine is only possible when the number of lights on the circuit is suited to the voltage of the dynamo. This is generally not the case, and the above arrangement is, therefore, of limited application and has

been used in comparatively few cases. Instead of supplying the lamps directly from the machine, a considerable range of applied E. M. F. may be obtained by using a constant-potential transformer with its secondary coil split up into a number of sections. The lamps are each provided with a reactance coil, as before, but the use of the transformer admits of a considerable range in the number of lamps that may be operated on a circuit; that is, the combined voltage necessary for the lamps may be considerably different from that generated by the alternator.

45. Operation From Constant-Current Transformers.—The method that has so far been most largely used for the operation of series alternating-current lamps from

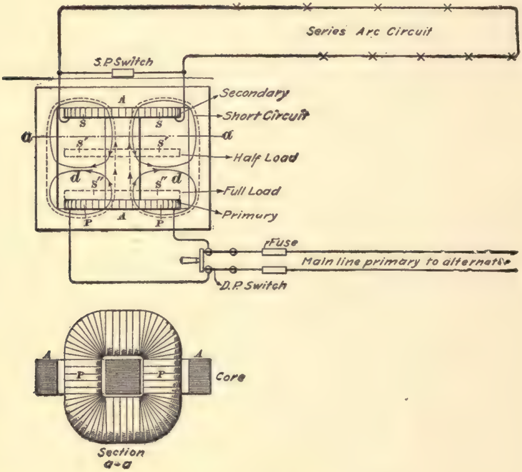


FIG. 21.

constant-potential alternators is that in which a special transformer is used to transform from constant potential to constant current. This means that the transformer must

be so constructed that its secondary voltage will change automatically as the number of lamps is changed. Fig. 21 illustrates the action of a transformer of this kind invented by Prof. Elihu Thomson and largely used in connection with series alternating-current lighting.

46. *A A* is a laminated iron core built up in the same way as a core for an ordinary transformer. *P P* is the primary coil wound so as to be thin and flat and surrounding the central part of the core, as shown in the sectional view. This coil is fixed in position and is attached to the lines leading to the alternator that maintains a constant or nearly constant pressure across the terminals of the coil. *S S* is the secondary coil, which is also thin and flat. This coil is free to move up and down. It is suspended from quadrants on the end of a lever and its weight is partially counterbalanced by weights hung on the other end. The terminals of the secondary are connected to the arc line by means of flexible cables that will not interfere with the free movement of the coil.

47. The action of the transformer is as follows: When the arc circuit is open and the primary is connected to the alternator, the secondary occupies the dotted position $S'' S''$ resting on the primary. The apparatus will then act like an ordinary transformer; an alternating magnetic flux will be set up through the core, as indicated by the curved dotted lines, and a high E. M. F. will be generated in $S'' S''$, although no current can flow in it because the secondary circuit is open. Let us now take the other extreme case, where the secondary is short-circuited by closing the single-pole switch connected across the arc line. As soon as the switch is closed, a heavy current will flow in the secondary coil and this current will be in the opposite direction to that flowing in the primary. It is a well-known fact that parallel wires carrying currents in opposite directions repel each other, and the result in this case is that the coil is repelled so that it moves up to the other extreme

position *S S*, shown by the full lines. When half the lamps are burning, the repulsion is sufficient to keep it in the mid-position *S' S'*.

As the secondary is repelled upwards, the E. M. F. generated in it decreases, because the current in the secondary tends to set up magnetism around the core in a direction opposite to that indicated by the dotted curved lines. The result is that lines of force pass across between the coils, as indicated by the full curved lines, and a large number of lines that thread through the primary coil do not pass through the secondary at all. Moreover, the farther the coils are separated, the greater does this leakage become. The result is that when the secondary reaches the top position *S S*, very little flux passes through it, and hence its E. M. F. becomes very small. By properly adjusting the counterbalancing of the coils, a transformer of this kind can be made to hold the current in the secondary constant within remarkably close limits through a wide range of load.

48. Fig. 22 shows one of the larger sizes of these transformers with the case removed. Here there are two fixed primary coils *P P* and *P' P'* and two movable secondaries *S S* and *S' S'*. The two secondaries are counterbalanced against each other by means of the levers, sectors, and chains shown in the figure, so that when the load is light both coils occupy a position near the center, and when it is heavy they both move towards the end coils. The weight *w* required to counterbalance the repulsion effect is carried by a small auxiliary lever *l* that projects through the top of the case. The two secondary coils may be connected in series to feed a single circuit, or they may be connected to two circuits, as in the multicircuit Brush dynamo. The whole transformer is placed in a corrugated cast-iron case filled with oil. This secures good insulation and makes the movements of the coils smooth, because the whole moving system acts like a dashpot.

49. Constant-current transformers may be placed either in the station or in a substation at a convenient point near

where the lamps are to be supplied. In some instances they have been placed in substations and equipped with automatic time switches that cut them out in the morning as soon as the lights are no longer needed. At light loads, a system of this kind has a poor power factor; but if

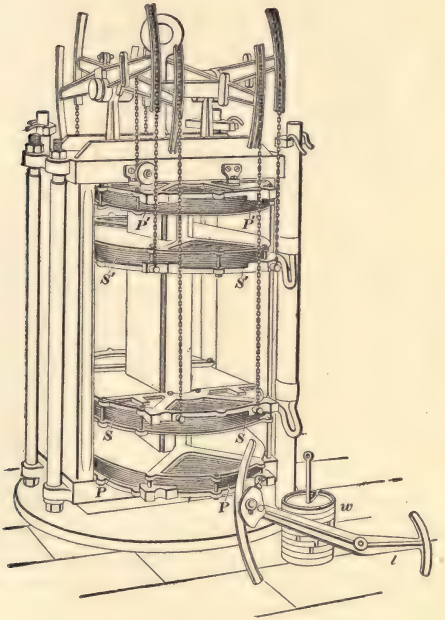


FIG. 22.

worked at nearly full load, the power factor is about .8, or about as good as the power factor of a load of induction motors. The low power factor has been urged as an objection against systems of this kind, and while it undoubtedly is an objection, it must not be forgotten that the doing away with arc-light dynamos and running all the lights,

both arc and incandescent, from the same kind of alternator is an advantage that goes far to outweigh the disadvantages of a low power factor.

50. Regulation by Means of Variable Reactance.—Fig. 23 shows another style of regulator for the operation of series alternating-current arc lamps from constant-potential circuits. It consists of a coil *C* mounted on the end of a lever and counterbalanced by the weight *W*. The laminated core *D* is ш shaped and the coil slides over the center tongue. When all the lamps are in operation, the

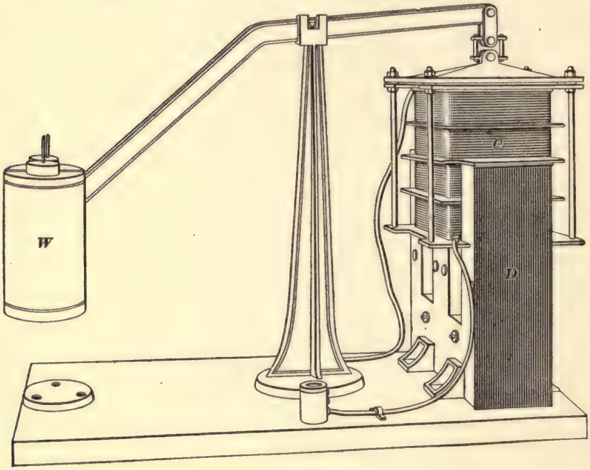


FIG. 23.

coil is balanced so that it is near the top of the core. If lights are cut out, the current tends to increase and the coil is pulled down. This increases the reactance of the coil, and the increased counter E. M. F. generated in it keeps the current down to its proper value. The regulator is connected directly in series with the arc circuit, as indicated in Fig. 24. At *A* the regulator is shown at the

station, the terminals of the arc circuit in this case being brought to the plant. At *B* the regulator is shown located at a convenient point out on the line. The terminals of the

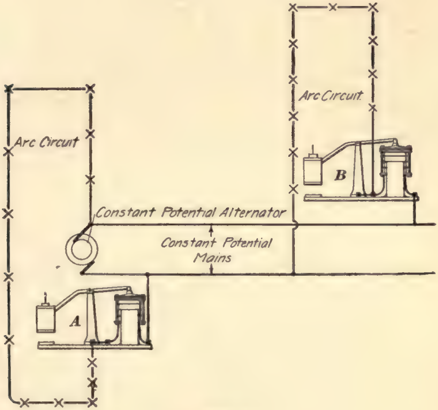


FIG. 24.

circuit are not carried back to the station. By adopting this latter arrangement, a saving in copper can sometimes be effected.

51. From what has been said with regard to lamps, dynamos, and the various systems of operation, it will be seen that there is a wide range of choice in the selection of apparatus. The examples that have been selected have been taken because they are the ones that have, on the whole, been most widely used and serve to bring out the main points connected with the principal systems of operation.

The introduction of the enclosed-arc lamp has changed the methods of arc lighting considerably within recent years and has been responsible for the steadily increasing use of alternating current for this purpose. The alternating-current open-arc lamp stood practically no chance

against its rival, the direct-current open arc, but the case is different with the enclosed-arc lamp. It is pretty generally admitted, however, that the alternating-current arc does not give quite as satisfactory all-around service as the direct-current arc; but the difference, at least so far as street lighting is concerned, is not great enough to prevent the introduction of the alternating-current arc for this purpose. In many cases, their use results in a much simpler and cheaper station equipment, which goes a long way to compensate for slight inferiorities in the light-giving qualities of the lamps.

ARC-LIGHT SWITCHBOARDS.

GENERAL CONSIDERATIONS.

52. Arc-light switchboards bear little resemblance to those used for constant-potential incandescent lighting. In most stations of any size, there are several arc machines and several circuits, and it is desirable to have the switchboard arranged so that any machine may be connected to any circuit. It is also necessary to arrange things so that a circuit may be transferred from one machine to another while in operation, or, if necessary, so that machines or circuits may be operated in series. An arrangement of switches to accomplish this would be exceedingly complicated, and arc-light boards are, therefore, of the plug variety. The various connections are made by inserting plugs into receptacles, the circuit being completed in some cases by flexible cables and in others by the plug itself.

53. Operating Circuits in Series.—Quite frequently, when the number of lamps in one circuit is insufficient to load up a dynamo, two or more circuits are connected in series, at the switchboard, with a single machine. The terminals of the circuits should be marked + and − on the switchboard, the + side being that at which the current leaves the

station and the − side that at which it returns. In connecting circuits in series, the − end of one circuit should be connected to the + end of the other, as indicated in Fig. 25. If two − ends are connected, the current will flow through the second circuit in the wrong direction and the lamps will burn "upside down."

The switchboard is usually equipped with an ammeter that will indicate when the current is flowing in the proper

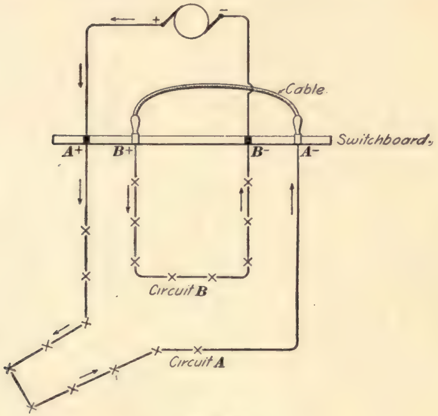


FIG. 25.

direction. Some of these ammeters, for example, the Weston, will not give a deflection over the scale unless the current flows in at the + terminal. Others have an indicating attachment that shows whether the current is flowing the wrong way or not. It goes almost without saying that series arc circuits are never connected in parallel. If this were done, the current would split between the circuits and the lamps would not operate properly. If the circuits are supplied with alternating current, they may be connected in series regardless of their polarity, as both carbons burn nearly alike in alternating-current lamps.

CONSTRUCTION AND OPERATION OF ARC SWITCHBOARDS.

54. Simple Board With Cables.—Fig. 26 illustrates about the simplest possible type of board equipped with an ammeter and terminals for two machines and four circuits. These terminals take the form of sockets or spring jacks mounted on the board, and connections are made between the various receptacles by means of heavily insulated, flexible cables provided with plugs at each end. Each terminal is double, and those for the dynamos are arranged in the lower row and marked $+A$, $-A$, $+B$, $-B$, each dynamo

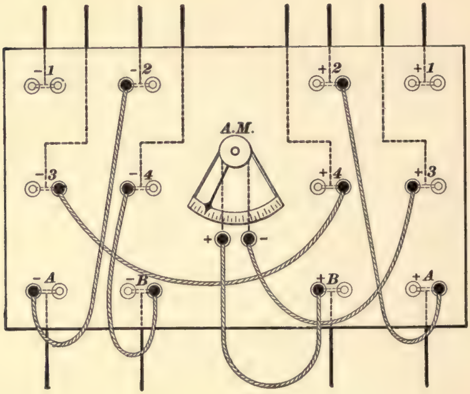


FIG. 26.

being distinguished by its letter A or B. The terminals of the four line circuits are arranged in two rows in the upper part of the board and are marked $+1$, -1, $+2$, -2, $+3$, -3, $+4$, -4, each circuit being distinguished by its number *1*, *2*, *3*, or *4*. The ammeter $A\ M$ is mounted in the center of the board and is provided with terminals $+$ and $-$. The board itself is usually made of a good quality of marble. Slate is not a good material for arc boards, as it is liable to contain metallic veins. It must be

remembered that the pressure between the terminals of an arc machine at full load is very high, hence the switchboard terminals must be well insulated. On most of the best boards the terminals are not even allowed to come into contact with the marble, but are insulated from it by means of hard-rubber bushings, the marble being used merely as a support and not depended on for insulation.

55. The operation of plugging in circuits or dynamos is a thing that always appears confusing to the student when an attempt is made to explain the method on paper. It is, however, comparatively easy to follow out on the board itself, where one can handle the cables and plugs and make the required connections for himself. A little practice during the daytime, when the circuits are not in use, will soon enable one to become so familiar with the method of operation that all necessary changes can be made quickly and with certainty.

In making changes on an arc board, it must be distinctly borne in mind that a circuit carrying current should never be broken in order to cut in or out line circuits containing lamps. If the circuit is opened, the effect is to suddenly increase the resistance of the circuit by a large amount, and the voltage will rise greatly. Besides causing a long, vicious arc at the switchboard and perhaps injuring the attendant, it is very hard on the insulation of the dynamo and may be the means of puncturing the insulation on an armature or field coil. If a dynamo or circuit is to be cut out, it should first be short-circuited. Arc machines are not injured by short-circuiting as constant-potential machines would be, because as soon as they are short-circuited the voltage generated drops to a very small amount. In Fig. 26, each terminal is made double, so that transfers may be made without opening the circuit.

In Fig. 26, circuit *1* is "dead," because its terminals are not connected to anything. Circuit *2* is on dynamo *A*, the path of the current being $+A - +2 - -2 - -A$. Circuits *3* and *4* are in series with each other on dynamo *B*, and the

ammeter is also in series in this circuit. The path of the current is $+B$, through the ammeter to $+3 - -3 - +4 - -4 - -B$.

56. Suppose that it is desired to connect the ammeter in circuit *2*. To disconnect it from circuits *3* and *4*, it is first short-circuited by plugging in a cable across the terminals $+B$ and $+3$. The two plugs on the cables leading to the ammeter may then be withdrawn from $+3$ and $+B$, and the circuit will not be opened. The plugs removed from $+B$ and $+3$ may then be inserted at $+A$ and $+2$, respectively, thus shunting the ammeter across the cable $+A$ $+2$. The cable $+A$ $+2$ is then removed and the current supplied to circuit *2* passes through the ammeter

57. Again, with the connections as shown in Fig. 26, suppose that it is desired to connect circuit *1* in series with circuit *2* without shutting down either the dynamo or circuit *2*. The first step will be to connect terminal -1 with terminal $+2$, then terminal $+A$ with terminal $+1$. The cable directly connecting terminal $+A$ and $+2$ may now be removed without opening the circuit at any point and at the same time throwing the two circuits *1* and *2* in series.

58. Board Without Cables.—Where a large number of machines and circuits are operated, the number of cables hanging around the front of the board becomes so great that they are in the way when transfers are being made. In order to overcome this objection, boards have been devised that do away with cables almost entirely. Some very large boards have been made on this plan. At present, the use of large multicircuit machines has resulted in a reduction of the number of dynamos needed for any one station, and there seems to be a tendency to go back to the style of board using cables. The simple cable board is no doubt cheaper than the other type and if properly built will give excellent service. Moreover, with the cable type of board the attendant can see at a glance just what connections he has made.

59. Fig. 27 illustrates the principle of one type of board made by the General Electric Company, in which cables are almost wholly dispensed with. This is accomplished by means of two groups of contacts arranged in two parallel planes a little distance apart. The contacts in the front group are divided into pairs of horizontal rows, each pair being connected to the terminals of one of the dynamos. The contacts on the back group are divided into pairs of

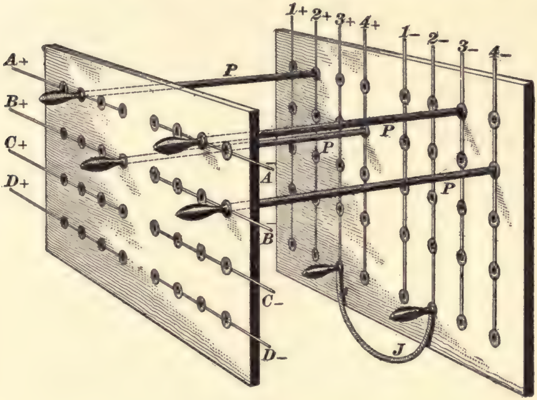


FIG. 27.

vertical rows, each pair being connected to one of the circuits. The contacts, which are in the form of split bushings, are directly opposite each other and the connection between any dynamo and any circuit is made by a long brass plug that is pushed through the outside contact to the inside. The arrangement will be clear by referring to Fig. 27. The dynamo terminals are lettered $A+$, $A-$, etc. and the circuit terminals $1+$, $1-$, as in the preceding case. The back or *circuit* board is provided with an extra row of contacts at the bottom, by means of which circuits may be connected in series, using for the purpose cables having suitable terminals, similar to those used for connections

in the form of board first described. In Fig. 27, the path of the current is as follows: $A+-2+-2--J-3+-3-A-$. Circuits *2* and *3* are in series on dynamo *A*. Also, we have circuit *4* on *B* because $B+$ and $B-$ are plugged through to $4+$ and $4-$. Circuit *1* is dead. By using a cable with short plugs that only reach through the front bushings, dynamos may be connected in series, if necessary.

60. In Fig. 27 the sets of bushings are shown separated much farther than they are on the actual board, in order to make the figure clear. On the actual board the back contacts are carried on vertical copper straps that are attached to the front board. Fig. 28 shows the general appearance

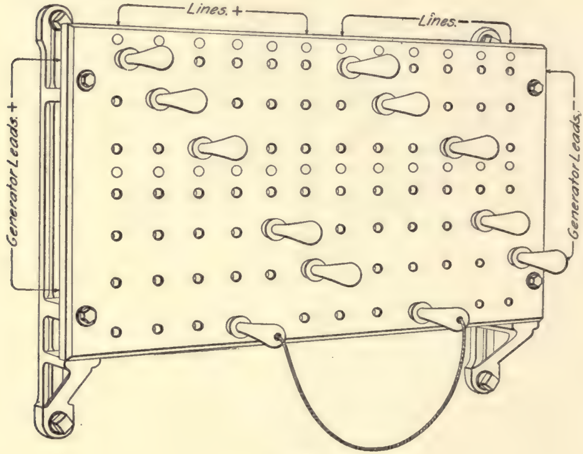


Fig. 28.

of one of these boards and indicates the location of the positive and negative terminals of the dynamos and circuits. Fig. 29 gives an idea as to the method of mounting the bushings and is self-explanatory. Bushings *b* are the ones used for connecting circuits in series. The board shown

in Fig. 28 has no ammeter; on some of the larger boards it is customary to connect an ammeter permanently in each circuit. In such cases they are usually mounted on a separate marble slab placed above the one carrying the contacts. The board shown in Fig. 28 is designed for six dynamos and six circuits.

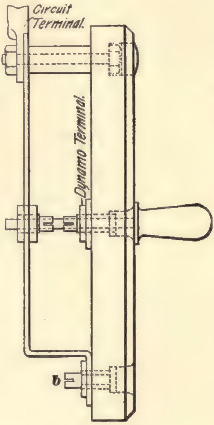


FIG. 29.

61. Panel Type Board. — This board is somewhat similar to the one last described. It is, however, designed so that it may be built up in panels in a manner similar to that described for incandescent-lighting boards, so that as more dynamos and circuits are needed the board may be extended by adding more panels. The general arrangement of the board will be understood by referring to Fig. 30 (*a*), (*b*), and (*c*). Referring to Fig. 30 (*c*), the lower terminals *b*, *c*, *d*, *e*, *f*, *g* are connected to the machines *A*, *B*, and *C*. The terminals at the top connect to the circuits *1'*, *2'*, and *3'*. The crosspieces *3*, *4*, *5*, *7*, *8*, and *9* run across the back of the board and may be connected to similar crosspieces on the next panel by means of the connection strips *3"*, *4"*, *5"*, etc. and plugs inserted in the side sockets *m*, *m*. An ammeter jack is connected in one side of each of the machines at the points *b*, *d*, and *f*, Fig. 30 (*a*). An ammeter cable that consists of two wires connected to a double contact plug on each end is provided. One plug is inserted into the ammeter jack at *b*, *d*, or *f* and the other end into jack *k*, thus connecting the ammeter in series with any one of the three dynamos.

Inserting the ammeter plug in the jack at *b*, for example, simply cuts the ammeter into circuit. When the plug is withdrawn, the jack closes the circuit before the plug is

fully drawn out, so that the circuit is not interrupted. The tubular supports *n*, shown in Fig. 30 (*c*), are of insulating material, and the plugs pass through them to make contact with the vertical strips. It will be noticed that there are three breaks in each vertical strip between a dynamo terminal and a corresponding circuit terminal. These breaks are at *l*, *l'*, *l''*. When, therefore, these breaks are plugged across, as indicated by the three rows of plugs in Fig. 30 (*a*),

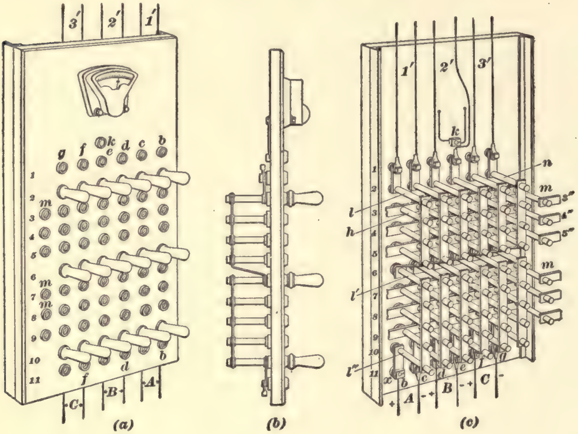


FIG. 30.

dynamo *A* is operating circuit *1'*; dynamo *B*, circuit *2'*; dynamo *C*, circuit *3'*. This will be apparent by referring to Fig. 31. The vertical lines here represent the vertical bars, in which the breaks are indicated by open spaces. The black circles represent the plugs, and are supposed to connect the two terminals between which they are inserted. Fig. 30 represents the ordinary condition of running, and it will be noticed that the cross-bars are not in use.

62. Suppose that it is desired to shut down machine *B* and run circuits *1'* and *2'* in series on machine *A*. Insert

plugs at c_6, d_6, c_7, and d_7 and remove plugs c_8 and d_8. This leaves two circuits and two machines in series. Short-circuit machine *2* by inserting a plug at e_7. Then cut out machine *2* by removing plugs d_{10} and e_{10}. Then take out plug d_7, and the board will be as indicated in Fig. 32. The path of the current will now be $A + - b_{10} - b_6 - b_2 - 1' +$ through circuit $1'-1' - - c_2 - c_5 - d_5 - d_2 - 2' +$ through circuit $2'-2' - - e_2 - e_6 - e_7 - c_7 - c_{10} - A -$ and circuits $1'$ and $2'$ are in series on dynamo A.

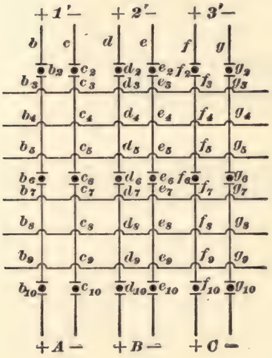


FIG. 31.

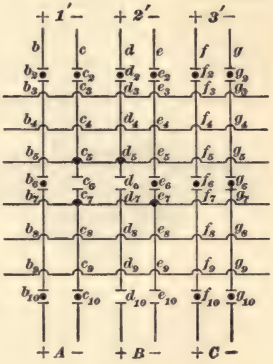


FIG. 32.

Although the combinations on these boards are not so easy to follow out from a diagram, the manipulation of even a large board is something that is soon learned when one has the board actually before him. The two things that are most important to bear in mind are always short-circuit a dynamo or circuit before cutting it out, and never open a circuit when the current is on.

63. Brush Plug and Spring Jack.—As stated above, in some of the boards used with large multicircuit machines, the ordinary cable method of connection is used. Another feature of modern arc boards is that no live metal parts are allowed on the surface where they might happen to be

touched by the attendant. These precautions are especially necessary for boards that are used with large arc machines, some of which generate 10,000 or 11,000 volts.

Fig. 33 illustrates the style of plug used on Brush arc boards. It will be noticed that pains are taken to secure high insulation. *A* is the marble panel and *b* the metal plug, or contact, attached to the cable as shown. *C* is a cup-shaped casting to which the line is connected and into which *b* slides and is held, so as to make a good contact by the spring clip *s*. *C* screws on to the end of the hard-rubber bushing *D* and is separated from the marble by the insulating washer *E*. *F* is a hard-rubber sleeve, or tube, and *G*

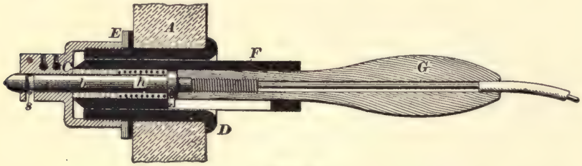


FIG. 33.

a maple handle; *h* is a spiral spring that causes the sleeve *F* to slide over the contact piece *b* when the plug is pulled out, so that by the time the plug is pulled entirely out of the board, the contact *b* is completely covered and there is no danger of the attendant coming into contact with it. When a plug is inserted, the nose of the sleeve *F* comes against casting *C*, and as the plug is pushed on in, contact *b* passes through the hole in *C* and is held by the spring *s*. These jacks are usually mounted in pairs connected together, so that transfers may be made without opening the circuit.

64. Western Electric Plug and Jack.—Fig. 34 shows an improved form of jack and plug that is used by the Western Electric Company. It consists of a main jack *A* and two smaller jacks *B*, *B*, which are used in making transfers. The springs *a*, *b*, *b* hold the plugs in place by engaging the groove on the end of the plug. This plug also has a hard-rubber sleeve *c* that slides over the metallic terminal *d*

as soon as the plug is pulled out. The general arrangement of the plug and jack will be apparent without further explanation.

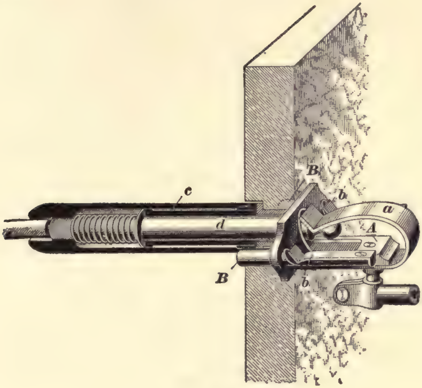


FIG. 34.

65. Ammeters.—An arc board requires comparatively little auxiliary apparatus. A single ammeter is about all that some boards are provided with, but others, equipped on a more elaborate scale, are provided with an ammeter for each machine. This ammeter is in general the same as those used for ordinary work except that its scale reads only to 10 or 15 amperes, the current for series lamps usually being from 6 to 10 amperes. The ammeter is always connected in circuit in the same manner as an arc lamp. Sometimes it is left in circuit all the time, but more often it is only cut in occasionally to find out if the current is right.

66. Voltmeter.—It is now common practice to equip arc boards with a high-reading voltmeter. This may be mounted in any convenient position and should be provided with flexible cables having well insulated terminals, so that the voltmeter may be connected across any circuit or dynamo. The voltmeter should have a range at least as high as the

highest pressure ever applied to any one circuit. The voltmeter enables the switchboard attendant to find out easily the number of lights in operation on any circuit, because he knows about the average number of volts required per lamp, and if the voltmeter is connected across the circuit, the reading obtained divided by the number of volts per lamp will show the number of lights in operation. A voltmeter to read as high as required for this work must have a very large resistance in series with it, and this makes the instrument rather expensive, but the expense is usually compensated for by the advantages gained by using the instrument. The voltmeter is also useful in detecting grounds on the line.

67. Wattmeters.—In the best stations it is customary to measure the electrical output of each machine so that the total electrical output of the plant may be determined and the cost of production per kilowatt-hour estimated. Sometimes the wattmeters are mounted by themselves near the machine; in other cases they are mounted on the switchboard. Any good type of recording instrument may be used, but the one that has found widest application in this direction is the Thomson recording wattmeter. The resistance in series with the armature of the meter must be very high, because the voltage of the machine is high at full load. For this reason, it is usually mounted in a box separate from the wattmeter, instead of being mounted in the wattmeter itself, as is done with those instruments intended for use on low-potential circuits only.

68. Lightning Arresters. — These should always be placed on arc circuits, as already described. Sometimes they are arranged on the switchboard or at the back of it, but more frequently they are set up at some convenient point near where the wires enter the station. No fuses or circuit-breakers are necessary on arc boards because the current is constant even if the lines or dynamos are short-circuited.

69. Transfer Boards.—It is highly important that all arc line wires brought into the station should be run as

straight and free from crossings as possible. A number of fires have resulted from the numerous crossings and the general maze of wires to be found in some of the older stations, especially at the point or in the tower where the wires enter the building. These crossings were generally made in order to bring the wires to the switchboard in the correct order for connecting up. In the best stations, it is

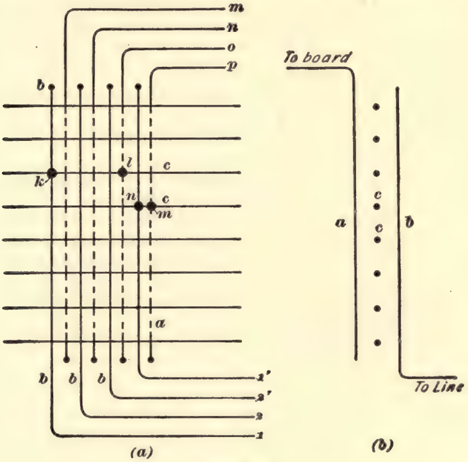


FIG. 35.

now usual to have, in addition to the switchboard, a **transfer board,** the object of which is to enable the lines running to the switchboard to be connected to any of the lines running out of the station. By using a transfer board, the wires coming into the station may be brought in in any order that may be most convenient, and they may be run straight to the board without crossings. They may then be sorted out and connected to any desired circuit terminals on the switchboard by using the transfer board. The transfer board is also very useful for changing the terminals of a circuit from one part of the board to another, as it enables

it to be done without disturbing the connections at the switchboard terminals themselves.

The general arrangement of the transfer board will be understood by referring to Fig. 35. A number of vertical wires *a* and *b* are stretched on a substantial framework. These wires are usually about No. 4 or 6 B. & S. and are bare. They are separated from 5 to 6 inches and are directly opposite one another, although in Fig. 35 (*a*) they have been shown a little to one side of each other in order not to confuse the connections. Between these vertical wires a corresponding number of horizontal wires *c* are also stretched. One set of vertical wires *a* runs directly to the circuit terminals on the switchboard and the other set *b* connects to the line wires.

The horizontal wires are used for connecting across from any line to any switchboard lead. For example, suppose *1* and *1'* are the terminals of a circuit and that we wish to connect them to switchboard leads *o*, *p*. By connecting to the cross-wire, as shown at *k*, *l*, line *1* is connected to *o*, and by connecting as shown at *m*, *n* line *1'* is connected to *p*. By this arrangement, therefore, the line and switchboard connections may be transferred in any way desired. The actual number of wires used in any case will, of course, correspond to the number of circuits to be accommodated. The connections between vertical and horizontal wires are usually made by means of a clamp

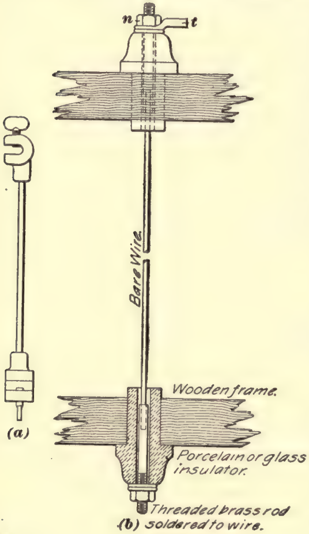


FIG. 36.

connector, somewhat similar to that shown in Fig. 36 (*a*). Different methods are used for stretching the wires on the frame, but they should always be mounted so that they will be thoroughly insulated. On this account the wire should be passed through porcelain or glass insulators at each end, as indicated in Fig. 36 (*b*). The wires are stretched tightly by screwing up on the nut *n* and the line wire attaches to terminal *t*.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS

TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

ALTERNATING CURRENTS.

(PART 1.)

EXAMINATION QUESTIONS.

(1) What is meant (*a*) by a cycle? (*b*) by an alternation?

(2) (*a*) What is meant by the frequency of an alternating current or E. M. F.? (*b*) What is meant when it is said that an alternating-current dynamo is a 60-cycle machine?

(3) What is the chief difference between a direct current and an alternating current?

(4) If an alternator generates an E. M. F. that passes through 15,000 alternations per minute, what is the frequency of the E. M. F. in cycles per second?

Ans. 125 cycles per sec.

(5) (*a*) When are two alternating E. M. F.'s or currents of the same frequency said to be in phase? (*b*) When are they out of phase?

(6) (*a*) Can two alternating currents that are in phase be added together in the same way as direct currents? (*b*) If an alternator supplies three circuits A, B, and C with 10, 20, and 25 amperes, respectively, and if the currents in all three circuits are in phase with each other, what is the total current furnished by the alternator? Ans. (*b*) 55 amperes.

(7) What is meant when it is said that one alternator is brought into synchronism with another?

(8) An alternator supplies two circuits A and B with currents of 8 amperes and 12 amperes, respectively. These two currents are not in phase with each other because one circuit supplies a load of lamps and the other a load of motors that have considerable self-induction. Will the total current supplied by the alternator be 20 amperes, and if not, will it be more or less than 20 amperes? Give reasons for your answer.

(9) If two currents are said to differ in phase by 60°, what part of a complete cycle does one lag behind the other?

(10) When are two alternating currents said to be in quadrature or at right angles to each other?

(11) What do you understand by (*a*) a two-phase system? (*b*) a three-phase system?

(12) A two-phase system is operated by means of three wires, the center wire serving as a common return. (*a*) If the current in each of the outside wires is 200 amperes, what will be the current in the common return wire? (*b*) If the voltage between each outside wire and the middle wire is 1,100, what will be the voltage between the two outside wires?

Ans. { (*a*) 282.8 amperes.
(*b*) 1,555.4 volts.

(13) Why is it not necessary to use a common return wire with a balanced three-phase system?

(14) An alternator supplies current to a balanced three-phase circuit. If at a particular instant the current in one wire A is at its maximum value of 100 amperes and is flowing *out* from the alternator, what is the amount and direction of the currents in the other two wires B and C?

Ans. 50 amperes flowing *in*.

(15) (*a*) What do you understand by the maximum value of an alternating current or E. M. F.? (*b*) What is

meant by the average value? (*c*) What is the relation between the average value and the maximum value for an ordinary smooth wave E. M. F. or current?

(16) (*a*) What is meant by the effective value of an alternating current? (*b*) What is its relation to the maximum value?

(17) (*a*) What is meant when it is stated that an alternating current of 50 amperes is flowing in a circuit? (*b*) What is the maximum value that the current reaches, and between what limits does the current alternate? (*c*) What is the average value of the current?

Ans. { (*b*) 70.7 amperes, +70.7 and −70.7.
(*c*) 45 amperes, nearly.

(18) (*a*) What do you understand by the E. M. F. of self-induction? (*b*) If a continuous current is allowed to flow steadily through a coil of wire that is wound on an iron core, is any self-induced E. M. F. set up, and if not, why?

(19) (*a*) What is meant by the coefficient of self-induction or inductance of an electrical circuit or device? (*b*) What unit is used to measure the coefficient of self-induction? (*c*) Would a coil wound on an iron core have a greater coefficient of self-induction than the same coil wound on a wooden core, and if so, why?

(20) What effect has self-induction in an alternating-current circuit as regards the phase relation of the current and E. M. F.?

(21) If an alternating current is sent through a circuit containing self-induction, (*a*) what phase relation does the E. M. F. *of* self-induction bear to the current? (*b*) What phase relation does the E. M. F. *to overcome* the self-induced E. M. F. bear to the current?

(22) If a current of 5 amperes at a frequency of 60 cycles per second is sent through a coil having an inductance of .02 henry, what will be the induced E. M. F. set up in the coil? Ans. 37.7 volts.

(23) An alternating current is sent through a circuit in which the induced E. M. F. is 20 volts and the E. M. F. necessary to overcome resistance is 8 volts. What must be the value of the impressed, or applied, E. M. F.?

Ans. 21.54 volts.

(24) (*a*) What is meant by the reactance of a circuit? (*b*) To what is the reactance equal? (*c*) What unit is used to measure reactance?

(25) (*a*) What is meant by the impedance of a circuit? (*b*) To what is the impedance equal? (*c*) In terms of what unit is impedance expressed?

(26) Give the formula showing the relation between the current, the applied E. M. F., and the impedance; in other words, give the form that Ohm's law assumes for alternating-current circuits.

(27) An alternator supplies current at 60 cycles to a circuit that has a resistance of 20 ohms and an inductance of .1 henry. The applied E. M. F. is 1,000 volts. Find (*a*) the reactance of the circuit; (*b*) the impedance; (*c*) the current that will flow under the applied pressure of 1,000 volts; (*d*) the current that would flow if the circuit had no self-induction.

Ans. { (*a*) 37.7 ohms, approximately.
(*b*) 42.7 ohms, approximately.
(*c*) 23.4 amperes.
(*d*) 50 amperes.

(28) What effect has electrostatic capacity on the phase relation of the current and the E. M. F. in an alternating-current circuit?

(29) If an alternator supplies current to any circuit or electrical device and if the current and E. M. F. differ in phase, can the number of watts expended be obtained by multiplying the number of volts by the number of amperes, as in the case of direct-current circuits, and if not, why?

(30) (*a*) What is meant by the power factor of an alternating-current circuit or device? (*b*) What is the value of

the power factor for direct-current circuits or for non-inductive, alternating-current circuits ?

(31) An alternating-current motor when carrying a certain load took 50 amperes at 100 volts, as measured by an ammeter and voltmeter. When a wattmeter was connected, it was found that the actual number of watts supplied was 4,200. What was the power factor of the motor for the given load ? Ans. .84.

ALTERNATING CURRENTS.

(PART 2.)

EXAMINATION QUESTIONS.

(1) (*a*) How is a squirrel-cage induction-motor armature constructed? (*b*) Explain how the currents are set up in such an armature.

(2) Why is it necessary to insert a resistance in series with either the armature or field of an induction motor when starting the motor?

(3) (*a*) What is an inductor alternator? (*b*) Does an inductor alternator require any moving wire or collector rings?

(4) How is the winding of a three-phase alternator arranged, i. e., how is the armature wound so as to generate three currents that differ in phase by 120°?

(5) (*a*) What is the difference between a core transformer and a shell transformer? (*b*) Why are the coils of transformers wound in sections and interleaved or else wound one over the other?

(6) If a two-phase rotary converter is supplied with alternating current at a pressure of 350 volts, what will be the pressure on the direct-current side? Ans. 495 volts.

(7) (*a*) How does the speed of an induction motor vary with the load? (*b*) What is meant by the slip of an induction motor?

(8) (*a*) What is meant by the ratio of transformation of a transformer? (*b*) A transformer has 600 turns on its primary and 60 turns on its secondary; if the primary is attached to 2,200-volt mains, what will be the secondary voltage? Ans. 220 volts.

(9) (*a*) Name the essential parts of an ordinary transformer. (*b*) Does a transformer ever deliver as much power from its secondary as it takes in from the primary? (*c*) What are the three sources of loss of power in a transformer?

(10) An alternator has sixteen poles and runs at a speed of 450 revolutions per minute. What is the frequency of the E. M. F. generated? Explain how you obtain your result. Ans. 60 cycles per sec.

(11) Name two things that cause the secondary voltage of a transformer to fall off when the transformer is loaded, and give reasons for their doing so.

(12) A three-phase rotary converter is to supply direct current at 110 volts for lighting purposes; with what alternating E. M. F. must it be supplied? Ans. 67.3 volts.

(13) Why is an induction motor so called?

(14) What two methods of connecting up the groups of coils on three-phase armatures are in common use? Explain each.

(15) (*a*) What do you understand by the *pitch* of an alternator? (*b*) Why should the breadth of the inside of the armature coils not be much, if any, less than the width of the pole face?

(16) An alternator is to be directly connected to a water-wheel running at 250 revolutions per minute and is to generate current at a frequency of 25 cycles per second; how many poles should the alternator have? Ans. 12 poles.

(17) (*a*) What is a synchronous motor? (*b*) How does its construction compare with that of an alternator? (*c*) Why will not a single-phase synchronous motor start up of its own accord when it is connected to the line?

(18) A synchronous motor has 10 poles and is operated by a 25-cycle alternator; what speed (R. P. M.) will the motor run at? Ans. 300 R. P. M.

(19) Why are open-circuit windings largely used for alternator armatures?

(20) Will changing the field strength of a synchronous motor alter the speed of the machine, and if not, why?

(21) How is it that a synchronous motor can take current from the line in proportion to its load without changing its speed?

(22) (*a*) What is a monocyclic alternator? (*b*) For what kind of work is the monocyclic alternator used? (*c*) If the pressure between the outside rings of a monocyclic alternator is 2,200 volts, what will be the pressure between the middle ring and each of the outside rings?

Ans. (*c*) 1,232 volts.

(23) How is the winding on an alternator arranged so that the machine will deliver two currents that differ in phase by 90°?

(24) (*a*) For what is the rectifier or commutator used on compound-wound alternators? (*b*) Does the rectifier change the direction of the current in the lines leading from the alternator, and if not, why?

(25) If a three-phase rotary converter is supplied with alternating current at 200 volts, what will be the pressure on the direct-current side? Ans. 326.8 volts.

ELECTRIC TRANSMISSION.

(PART 1.)

EXAMINATION QUESTIONS.

(1) (*a*) What is an ampere-hour meter? (*b*) Would an ampere-hour meter give an accurate indication of the actual power supplied to an induction motor, and if not, why?

(2) Why should transformers operated on constant-potential circuits be protected by primary fuses?

(3) (*a*) Draw a diagram showing how you would connect up an indicating wattmeter to measure the watts supplied to a direct-current motor. (*b*) What precaution must be taken in connecting up a wattmeter?

(4) Power is to be delivered over a line the total length of which (both ways) is 5 miles; 100 horsepower is to be delivered at the end of the line and the pressure at the distant end is to be 500 volts when the 100 horsepower is being delivered. The drop in the line must not exceed 50 volts under full load. Calculate the cross-section of the line wire and give your result in circular mils.

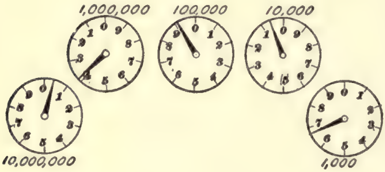
Ans. 850,800 circular mils, approximately.

(5) The reading of a customer's meter at the end of a month was 9,995,400, and at the end of the next month it was 230,200. If the constant of the meter were 2 and if the customer were charged 5 cents per kilowatt-hour for power, what would be his bill? Ans. $23.48.

(6) 30,000 watts are delivered over a direct-current transmission line, and when the line is carrying this load the pressure at the end where the power is delivered is 500 volts. (*a*) What is the current in the line? (*b*) If the voltage at the station at the time this load is being delivered is 525 volts, what is the drop in the line? (*c*) How many horsepower are lost in the line? (*d*) How many horsepower are supplied to the line at the power station?

Ans. { (*a*) 60 amperes.
(*b*) 25 volts.
(*c*) 2.01 H. P.
(*d*) 42.2 H. P.

(7) (*a*) What does the meter dial shown in the figure read (to the nearest hundred) and explain how you obtain the reading? (*b*) If the previous meter reading were 300,400 and the constant of the meter ½, how many watt-hours has the customer used since the last reading?



Ans. { (*a*) 390,700.
(*b*) 45,150.

(8) (*a*) Under what circumstances is direct current generally used for electric-power transmission? (*b*) When is alternating current used?

(9) (*a*) If the armature circuit of a Thomson recording wattmeter becomes broken, how is the operation of the meter affected? (*b*) What happens if the resistance in series with the armature becomes short-circuited? (*c*) Can an induction wattmeter be run on a direct-current circuit, and if not, why?

(10) A Thomson meter was tested by running it on a load of lamps and noting the revolutions made by the disk

in a given time. The watts, as calculated by formula **20**, were 630, and the watts indicated by the standard wattmeter, or ammeter and voltmeter, were 650. (*a*) What percentage too slow was the meter? (*b*) How could the trouble be remedied?

(11) The total length of a line of copper wire is 3 miles and the area of cross-section of the wire is 26,000 circular mils. What is the resistance of the line?

Ans. 6.58 ohms, nearly.

(12) (*a*) Make a sketch showing how you would connect three transformers on a three-phase system with both their primaries and secondaries connected Δ. (*b*) If the primary voltage were 1,100 and if the transformers were wound for a ratio of 10 to 1, what pressure would be obtained between the secondary mains? Ans. (*b*) 110 volts.

(13) (*a*) What is meant by the "drop" in a transmission line? (*b*) On what quantities does the "drop" depend in an ordinary direct-current transmission line?

(14) 500 kilowatts are to be delivered over a line 10 miles long (one way) to a load consisting of motors and lights. The three-phase system (60 cycles) is to be used and the loss in the line is to be limited to 10 per cent. of the power delivered, and the voltage at the end of the line is to be 10,000. Calculate (*a*) the full-load current in each line; (*b*) the size of line wire in circular mils and the nearest size B. & S.; (*c*) the volts drop in the line.

Ans. (*a*) 33.95 amperes.
(*b*) 39,600 circular mils, or No. 4 B. & S.
(*c*) 1,000 volts.

(15) A wire is .016 inch in diameter; what is its area of cross-section in circular mils? Ans. 256 circular mils.

(16) (*a*) What is an indicating wattmeter? (*b*) What is a recording wattmeter? (*c*) What does a recording wattmeter register?

(17) Name some of the advantages of alternating currents that render them well suited for the transmission of power over long distances at high pressures.

(18) A Thomson recording wattmeter when tested made 15 revolutions of the disk in 1 minute and 20 seconds. If the constant of the meter was 2, what was the average number of watts being expended in the circuit?

Ans. 1,350 watts.

(19) (*a*) What is a mil? (*b*) What is a circular mil?

(20) The power factor of a 500-volt three-phase induction motor is .80, and at full load the motor takes 25 horsepower from the line. What will be the full-load current in each line? Ans. 26.9 amperes.

(21) (*a*) Why is single-phase alternating current not used to any great extent for power-transmission work? (*b*) For what class of work is it used?

(22) Do alternating-current lines have a greater self-induction when they are strung wide apart than when strung close together, and if so, why?

(23) Would it be practicable to connect two transformers on a two-phase system with their primaries connected across the two different phases and their secondaries in parallel with each other, and if not, why?

(24) Why are two-phase or three-phase systems used when power is to be transmitted by means of alternating current?

(25) Why is direct current not suited for the transmission of power over long distances?

(26) (*a*) Make a sketch showing how you would connect two transformers on a three-phase system. (*b*) Is this arrangement as good as the one using three transformers, and if not, why? (*c*) If you had to install three transformers to operate a 50-horsepower motor on a three-phase system, what capacity of transformers would you use?

(27) If it takes a No. 0000 wire to transmit 20 horsepower over a given distance with a drop of 10 per cent. of the terminal pressure of 200 volts, what size wire would it take to transmit the same amount of power over the same distance with the same percentage loss if a terminal pressure of 400 volts were used? Ans. No. 3 B. & S.

(28) Why is it generally not advisable to operate a number of small transformers in parallel?

(29) What advantage has the three-wire direct-current system over the two-wire system?

(30) (*a*) What style of conductor is generally used for ordinary overhead transmission lines using moderate pressures? (*b*) What style of conductor is used for underground work?

(31) (*a*) Make a sketch showing how you would connect two transformers on a single-phase system so as to feed three-wire secondary mains. (*b*) How would you test the secondary mains to see if you had made the right connections?

(32) (*a*) Make a sketch showing how you would connect two transformers with their primary coils in parallel across the mains and their secondaries also in parallel. (*b*) Name some of the precautions that should be taken when connecting transformers in this way.

ELECTRIC TRANSMISSION.

(PART 2.)

EXAMINATION QUESTIONS.

(1) (*a*) What cross-section per ampere should be allowed for the + and the – leads running from a dynamo to the switchboard? (*b*) What cross-section per ampere should be allowed for the equalizer?

(2) (*a*) About what is the minimum size of pole top that should be allowed in good construction? (*b*) About how many poles should be used per mile?

(3) Name some of the advantages and disadvantages of porcelain insulators as compared with glass insulators.

(4) What style of insulator is commonly used for ordinary work using moderate pressures?

(5) What are some of the distinguishing features of the Edison underground-tube system?

(6) Why is it usually desirable to have manholes ventilated?

(7) What conditions must be attained before two alternators can be thrown in parallel?

(8) The insulation resistance of an electric-light system was measured by means of a voltmeter having a resistance of 17,000 ohms. When connected across the circuit, the voltmeter read 120 volts, but when connected between one line and the ground, it indicated 5 volts. What was the insulation resistance of the system? Ans. 391,000 ohms.

(9) Suppose power is supplied on the three-phase system over a three-wire underground cable 12,000 feet long. A ground develops on one of the wires and the Varley loop test is applied to locate the ground, one of the other wires being used as a good wire to make the necessary connections. One end of the battery was grounded as in Fig. 38, and the bridge was balanced with $m = 10$ ohms; $n = 1{,}000$ ohms; and $p = 162$ ohms. Where was the ground if the resistance of each wire in the cable was .123 ohm per 1,000 feet?

Ans. 10,724 ft.

(10) How could you find out whether two alternators were in synchronism or not?

(11) How would you locate a partial ground on a wire in case a good wire were not available to aid in carrying out the test?

(12) (*a*) Should lightning arresters be installed in the station only, or should they be placed at intervals along the line? (*b*) Does a lightning arrester arrest the discharge; if not, what does it do?

(13) Why must lightning arresters be provided with an arrangement of some kind to suppress arcing?

(14) Can alternators be run in series, and if so, under what conditions?

(15) (*a*) Can two compound-wound dynamos be run in parallel? (*b*) Is an equalizing connection necessary, and if so, what points should it connect?

(16) (*a*) Can compound-wound dynamos be run in multiple with shunt-wound dynamos? (*b*) If it were necessary to run machines in this way, what would you do?

(17) Why will a lightning discharge leap across an air gap in preference to passing through an inductive path?

(18) For what are kicking coils, or reactance coils, used in connection with lightning arresters?

(19) Can two compound-wound machines be made to divide the load properly between them by varying the

shunts across their series coils, and if not, how can they be made to divide the load in the proper proportion?

(20) If two compound-wound dynamos of unequal capacity are to be run in parallel, what relation must exist between the combined resistance of their series coils and connections to the bus-bar?

(21) Will shunt-wound dynamos operate well in parallel, and if so, why?

(22) (*a*) Why are two plain series dynamos, run in parallel, unstable in operation? (*b*) How can the unstable condition be remedied in large measure?

(23) (*a*) About what voltage is required per cell for charging a storage battery? (*b*) What voltage is obtained per cell on discharge? (*c*) Below what voltage should cells not be discharged?

(24) Does a storage cell store up electricity? If not, what does it do?

(25) (*a*) How is the capacity of a storage battery usually expressed? (*b*) If a battery is discharged at a high rate, will its total output be diminished?

(26) (*a*) How is the true efficiency of a storage battery obtained? (*b*) What is the ampere-hour efficiency? (*c*) Why is the watt-hour efficiency always less than the ampere-hour efficiency?

(27) When a storage cell is charged, what is formed on (*a*) the positive plate? (*b*) the negative plate? (*c*) What changes do these substances undergo when the cell is discharged?

(28) What is meant by the positive plate of an ordinary storage cell?

(29) What is the difference between a Planté type, or formed storage cell, plate, and a Faure, or pasted, plate?

ELECTRIC LIGHTING.

(PART 1.)

EXAMINATION QUESTIONS.

(1) Explain the action of a frequency changer.

(2) (*a*) Make a sketch showing how you would connect two large transformers on a single-phase system to feed three-wire secondary mains. (*b*) What are some of the advantages gained by supplying customers from secondary mains rather than from a number of small transformers?

(3) (*a*) How are incandescent lamps generally connected? (*b*) How are they sometimes connected on 220-volt and 500-volt power circuits?

(4) Describe briefly two methods of operating a three-wire system by means of a single 220-volt dynamo with auxiliary apparatus to take care of the balancing.

(5) (*a*) Name the principal parts of an incandescent lamp. (*b*) Of what is the filament made? (*c*) What material is used for the leading-in wires and why is this material used?

(6) (*a*) What three styles of lamp base are in most common use? (*b*) Which one of the three is used to the greatest extent?

(7) (*a*) What is the common unit used for expressing the brightness of a source of light? (*b*) To how many Hefner units is 1 standard candle equal?

(8) (*a*) What is a photometer? (*b*) Describe the Bunsen photometer.

(9) A photometer bar is divided into 500 equal parts and a standard lamp of 32 candlepower is placed at one end. The lamp to be measured is placed at the other end, and it is found that the screen becomes balanced when it is 350 divisions from the standard. What is the candlepower of the lamp under test? Ans. 5.88 c. p.

(10) (*a*) What is meant by the mean horizontal candlepower of an incandescent lamp? (*b*) How is the mean horizontal candlepower usually measured?

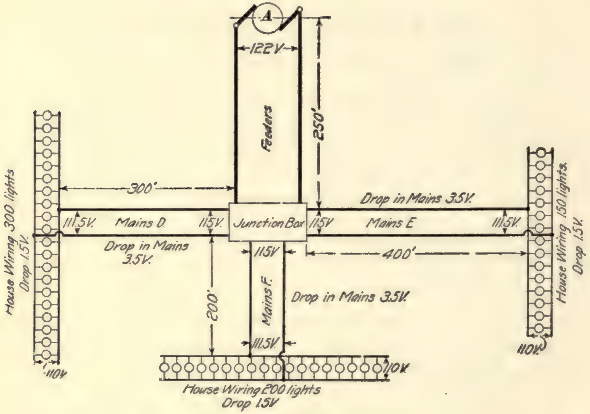


FIG. I.

(11) (*a*) At about what temperature is the filament of an incandescent lamp worked? (*b*) What is a fair value for the number of watts consumed per candlepower of an ordinary incandescent lamp?

(12) About how many 16-candlepower lamps can a 30-kilowatt dynamo run? Ans. 500.

(13) (*a*) What is the feeder-and-main system of distribution? (*b*) What are its advantages?

(14) Describe the Westinghouse method of operating incandescent lamps in series on constant-potential alternating-current systems. Illustrate by means of a sketch.

(15) Fig. I shows a two-wire 110-volt system, the number of lamps operated and the various distances being as shown. The total allowable drop from the dynamos to the lamps is not to exceed 12 volts. The drop in the house wiring is to be 1.5 volts, the drop in the mains 3.5 volts, and the balance of the drop is taken up in the feeders. Calculate the size of wire required for (*a*) the feeders; (*b*) the mains *D*; (*c*) the mains *E*; (*d*) the mains *F*.

Ans. { (*a*) 250,714 cir. mils.
(*b*) 277,714 cir. mils.
(*c*) 185,143 cir. mils.
(*d*) 123,428 cir. mils.

(16) If a certain object is 10 feet from a source of light, how many times will the illumination on it be reduced if it is moved to a distance of 35 feet from the source?

(17) In making photometer tests on incandescent lamps, what three requirements should be fulfilled in order that the photometer screen may be set with a fair degree of accuracy?

(18) (*a*) Is the hot resistance of an incandescent lamp greater or less than the cold resistance? (*b*) What is the approximate hot resistance of an ordinary 16-candlepower 110-volt lamp?

(19) A 32-candlepower 220-volt lamp requires 4 watts per candlepower. What current will 160 of these lamps take on an ordinary two-wire system? Ans. 93.09 amperes.

(20) (*a*) What do you understand by mean spherical candlepower? (*b*) Are incandescent lamps usually rated by their mean spherical candlepower?

(21) The pressure on a long-distance electric-light feeder is to be raised 25 volts by means of a booster. The maximum current to be supplied to the feeder is 500 amperes. What must be the capacity of the booster in kilowatts?

Ans. 12.5 K. W.

(22) Draw a simple diagram showing how to connect a shunt-wound booster so as to raise the pressure on a two-wire circuit.

(23) Fig. II shows a three-wire system. The main feeders C run to a junction box J, from which current is distributed to the house wiring F by means of the mains D. Current is also supplied from J to the lamps E uniformly distributed as shown. The drop in the feeders C (i. e., the drop on one side of the circuit) is to be 5 per cent. of the

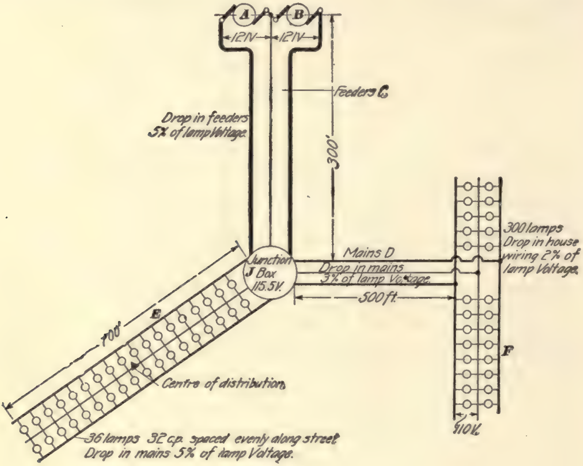


Fig. II.

lamp voltage, and that in the mains D 3 per cent. of the lamp voltage; the drop in mains E is to be 5 per cent. of the lamp voltage. The distances and number of lamps supplied are as shown on the figure. Calculate (*a*) the size of feeders C; (*b*) the size of mains D; (*c*) the size of mains E.

Ans. { (*a*) 54,785 cir. mils.
(*b*) 122,727 cir. mils.
(*c*) 12,371 cir. mils.

(24) (*a*) What voltages are ordinarily used for operating incandescent lamps? (*b*) Give a table showing the approximate current required by some of the ordinary sizes of lamps.

(25) Three thousand 16-candlepower incandescent lamps are to be operated at a point 20,000 feet from the station The total loss in power is to be limited to 15 per cent., 10 per cent. of which is to be lost in the transmission line and 5 per cent. in the secondary wiring and transformers. The lamps require 3.5 watts per candlepower, and the voltage at the end of the line is to be 4,000. Find the size of the line wires required if the three-phase alternating-current system is used. Ans. 26,460 cir. mils; a No. 6 B. & S.

ELECTRIC LIGHTING.

(PART 2.)

EXAMINATION QUESTIONS.

(1) Name three of the principal ways in which storage batteries may be used to advantage in connection with lighting plants.

(2) Describe the action of the Stanley electrostatic ground detector.

(3) Give a list of the most important instruments and appliances used on a lighting switchboard.

(4) (*a*) For what are potential regulators used in lighting plants? (*b*) Describe the action of the Stillwell regulator.

(5) (*a*) How many field rheostats are generally used for each alternator on an alternating-current switchboard? (*b*) Where are these rheostats connected? (*c*) Is one field rheostat in series with the shunt field of the exciter sufficient to control the field excitation of an alternator?

(6) (*a*) Make a sketch showing how three lamps may be connected so as to indicate grounds on a three-wire system. (*b*) Describe the action of the lamps when a ground takes place on each of the lines.

(7) (*a*) For what are current transformers used? (*b*) Make a sketch showing how a current transformer would be connected.

(8) (*a*) Draw a diagram and describe the action of the two-lamp ground detector as used on ordinary two-wire direct-current circuits. (*b*) Why is a voltmeter to be preferred to lamps for the detection of grounds?

(9) (*a*) What style of switch is commonly used for low-pressure lighting switchboards? (*b*) Name some styles that are used on high-pressure alternating-current boards.

(10) What method is used for extinguishing the arc in the Garton lightning arrester?

(11) Make a sketch and describe the operation of the Westinghouse lamp ground detector as used on alternating-current circuits.

(12) Make a sketch showing how you would connect three Wurts 1,000-volt alternating-current arresters on a 3,000-volt line.

(13) Why are fuses being superseded by circuit-breakers on lighting switchboards?

(14) The bus-bars of a lighting switchboard have to carry 1,300 amperes. What should be the cross-section of the bars and give the dimensions of a bar that would answer?

Ans. About 1.3 sq. in., or 3 in wide by $\frac{7}{16}$ in. thick.

(15) What are pressure wires and for what purpose are they used?

(16) (*a*) What is an electrostatic voltmeter? (*b*) Does an electrostatic voltmeter require any current for its operation?

(17) (*a*) For what are potential transformers used? (*b*) Make a sketch showing how a potential transformer is connected.

(18) Explain the action of the Thomson inclined-coil type of alternating-current ammeter.

(19) What is an ammeter shunt and for what purpose is it used?

(20) (*a*) Is it necessary to equip each dynamo in a lighting station with an ammeter, and if so, why? (*b*) Is it necessary to equip each feeder with an ammeter?

(21) If the equalizer is connected to the positive side of a machine, in which side should the ammeter be connected? Give reason for your answer.

(22) (*a*) For what are pilot lamps used? (*b*) Should they be connected back of the main switch, i. e., between the main switch and the dynamo, and if so, why?

(23) How is the voltage of storage batteries used in lighting plants usually regulated?

(24) Draw a diagram showing how you would connect two compound-wound direct-current dynamos for parallel operation. The machines are to feed four circuits, each circuit being provided with a main switch and fuses. Each dynamo is to be provided with a main switch, circuit-breaker, ammeter, voltmeter plug, and pilot lamp. Also provide one voltmeter for connection to either dynamo.

(25) (*a*) For what are compensators used? (*b*) Explain the action of the Mershon compensator.

ELECTRIC LIGHTING.

(PART 3.)

EXAMINATION QUESTIONS.

(1) Describe the general construction of a horizontal type ratchet-feed searchlight lamp.

(2) Name some of the things that will cause burned-out shunt coils in series arc lamps.

(3) What are some of the main points of difference between an alternating-current constant-potential arc lamp and a direct-current constant-potential lamp?

(4) What should be the length of arc (*a*) for a 2,000-nominal candlepower series arc lamp? (*b*) for a 1,200-nominal candlepower lamp?

(5) What is likely to happen if constant-potential enclosed-arc lamps are operated on a higher voltage than that for which they are adjusted?

(6) (*a*) What kind of wire is generally used for arc-light lines? (*b*) Why is it advisable to have an arc-light line divided into loops that can be cut out by means of switches?

(7) (*a*) What is meant by a carbon-feed enclosed-arc lamp? (*b*) What are some of the advantages and disadvantages of a carbon feed?

(8) At what current and voltage are series enclosed-arc lamps commonly operated?

(9) (*a*) Why is a single coil in series with the arc incapable of regulating a series constant-current arc lamp? (*b*) Explain the action of a simple differential series arc lamp.

(10) Explain the action of a simple constant-potential lamp.

(11) Make diagrams showing how to connect arc lamps on (*a*) a direct-current constant-potential system, and (*b*) a constant-potential alternating-current system.

(12) (*a*) Why is it necessary to have an automatic cut-out in series arc lamps? (*b*) Why is it necessary to use a starting resistance in some styles of series arc lamp?

(13) How is the regulation of the Thomson-Houston series arc lamp brought about? Is this a differential lamp or is the feeding action controlled by the shunt coils alone?

(14) (*a*) How may the voltage at the arc on a General Electric constant-potential direct-current enclosed-arc lamp be adjusted? (*b*) How may the voltage be adjusted on the General Electric constant-potential alternating-current lamp?

(15) (*a*) What system of distribution is used almost exclusively for street lighting by means of arc lamps? (*b*) How are lamps switched out on such a circuit? (*c*) How must the voltage of the dynamo supplying such a circuit vary with the load? (*d*) Does the current vary, and if not, how is it kept constant?

(16) (*a*) What is a multicircuit arc machine? (*b*) Explain, by means of diagrams, the operation of two arc circuits from one machine and point out the advantages that are claimed for this method of operation.

(17) How many watts, approximately, do the following lamps consume: (*a*) a 2,000 nominal candlepower open-arc lamp? (*b*) a 1,200 nominal candlepower open arc?

(18) (*a*) Of what are ordinary arc-lamp carbons generally made? (*b*) Why do enclosed-arc lamps require a higher

grade of carbon than open-arc lamps? (*c*) What material is generally used for making enclosed-arc lamp carbons?

(19) (*a*) Make sketches showing at least three of the different methods of arranging the carbons for searchlights or other projection apparatus. (*b*) What is a Mangin mirror?

(20) (*a*) In direct-current lamps why should the upper carbon always be connected to the positive side of the line? (*b*) How would you find out whether a lamp were burning "upside down" or not?

(21) Does the direct-current enclosed arc form a well-defined crater like the direct-current open arc, and if not, what shape do the carbon points assume?

(22) What amount of current do open-arc direct-current series lamps usually take?

(23) (*a*) What is an enclosed arc? (*b*) How does the consumption of carbon in an enclosed arc compare with that in an open arc? (*c*) Give a description of the general arrangement of an enclosed arc.

(24) What are the characteristic features of a direct-current arc formed in open air between carbon points?

(25) (*a*) What is the approximate temperature of the electric arc? (*b*) Does an arc lamp using a large current produce a higher temperature at the arc than one using a small current? (*c*) What is the effect of increasing the current supplied to an electric arc?

(26) (*a*) In what direction does an open-arc direct-current lamp throw the greatest amount of light? (*b*) Why should reflectors be used with alternating-current arc lamps?

ELECTRIC LIGHTING.

(PART 4.)

EXAMINATION QUESTIONS.

(1) In Fig. 31, where would the plugs be inserted if machine A were connected to circuit $1'$ and if machine C were running circuits $2'$ and $3'$ in series, machine B being shut down?

(2) Draw a diagram showing how you would connect a pair of Thomson lightning arresters on an arc-light circuit.

(3) How would you cut out an open-circuited coil on an arc machine having a closed-circuit ring armature?

(4) (*a*) Into what two classes may constant direct-current arc machines be divided? (*b*) Name some common makes of machine belonging to each of the classes.

(5) For what are transfer boards used in connection with arc-light switchboards?

(6) How would you locate a ground on an arc line by using a voltmeter?

(7) Give a general description of the method by which a Brush arc machine, equipped with an oil regulator, is made to regulate for constant current.

(8) Name some of the chief points of difference between the new and old styles of Brush arc dynamo.

(9) Name some of the precautions to be taken when connecting up circuits and dynamos on an arc plug switchboard.

(10) Why is it necessary to provide constant direct-current arc machines with a regulator?

(11) On the board shown in Fig. 27, what would be the position of the plugs when machine *A* is operating circuit *1* alone, circuit *2* being dead, machine *B* operating circuits *3* and *4* in series, and machines *C* and *D* being shut down?

(12) If alternating-current series arc lamps are to be operated, is the alternating current usually generated at constant potential or constant current?

(13) What is the characteristic feature of flashing at the brushes of an arc machine when it is caused by an open circuit in the shunt coils of one or more of the lamps?

(14) Describe the principle and action of the Thomson constant-current transformer.

(15) About what should be the length of spark at the brushes on a T. H. machine when running under normal conditions?

(16) Name some of the different methods that may be used for operating series arc lamps from constant-potential alternators.

(17) Give some of the defects that will lead to flashing on a T. H. arc machine.

(18) Describe the method of locating a break in an arc-light line by using a magneto-bell.

(19) (*a*) Why is it that in some cases two arc machines will not regulate well when run in series? (*b*) How would you remedy matters?

(20) Name some of the defects that will give rise to excessive sparking at the brushes of a T. H. arc dynamo.

(21) How would you right matters if the polarity of a series arc machine should become reversed?

(22) For what purpose is a rheostat sometimes used in shunt with the field of a Thomson-Houston arc dynamo?

(23) Describe how you would locate a ground on an arc-light line by using a magneto-bell.

(24) If a coil on an armature is cut out on account of a short circuit in it, why should the coil be rewound before an attempt is made to operate the machine?

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

CONTAINED IN THE

EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the course.

ALTERNATING CURRENTS.

(PART 1.)

(1) (*a*) A cycle is the complete set of values that an alternating current or E. M. F. passes through repeatedly.

(*b*) An alternation is the set of values represented by a half wave or half cycle. See Art. **9.**

(2) (*a*) The frequency is the number of complete cycles passed through in a given interval of time. The interval of time used is generally the second, so that the frequency may be defined as the number of cycles that the current passes through per second.

(*b*) A 60-cycle alternating-current dynamo is one that generates an E. M. F. that passes through 60 cycles per second. See Art. **8.**

(3) A direct current always flows in the same direction, whereas an alternating current is continually reversing its direction of flow.

(4) 15,000 alternations per minute are equal to 7,500 cycles per minute, because each alternation is half a cycle. 7,500 cycles per minute are equal to 125 cycles per second. Ans.

(5) (*a*) Two alternating currents or E. M. F.'s of the same frequency are said to be in phase when they come to their maximum values at the same instant. See Fig. 7, Art. **10.**

(*b*) They are out of phase when they do not come to their maximum values at the same instant. In order for there to be a difference of phase, we must always have under consideration at least two currents, two E. M. F.'s, or one

current and an E. M. F.; that is, two or more currents may differ from each other in phase, or two or more E. M. F.'s may differ in phase, or we may have a phase difference between currents and E. M. F.'s. See Art. **11.**

(6) (*a*) Yes. See Art. **13.**

(*b*) Since the currents are in phase, the total current furnished by the alternator will be the sum of the three separate currents, i. e., $10 + 20 + 25 = 55$ amperes.

(7) It means that the E. M. F. of the second is brought to the same frequency as that of the first machine, and also that its E. M. F. is brought into phase, or into step, with the E. M. F. of the first machine. See Art. **12.**

(8) The total current furnished by the alternator will not be 20 amperes, but will be some amount less than 20 amperes, depending on how much the currents of 8 and 12 amperes differ in phase. Since the two currents are not in phase, there are intervals when they oppose each other, and, consequently, the resultant current is less than their sum. It is evident that if the currents were exactly opposite in phase, the total current would be but $12 - 8 = 4$ amperes. See Art. **14.**

(9) Since one whole cycle is represented by 360°, a phase difference of 60° would mean one-sixth of a complete cycle. See Art. **16.**

(10) When they differ in phase by 90°, or one-quarter of a complete cycle. See Art. **17.**

(11) (*a*) A two-phase system is one that makes use of two simple alternating currents that differ in phase by 90°, or one-fourth of a complete cycle.

(*b*) A three-phase system is one that makes use of three simple alternating currents that differ in phase by 120°, or one-third of a cycle. See Art. **20.**

(12) (*a*) From Art. **19** we see that the current in the middle wire is 1.414 times the current in the outside wires; hence the current in the middle wire $= 200 \times 1.414 = 282.8$. Ans.

(*b*) Also the voltage between the outside lines is 1.414 times the voltage on each phase, hence the voltage between the outside lines = 1,100 × 1.414 = 1,555.4 volts. Ans.

(13) Because the sum of the three currents is at all instants equal to zero; i. e., one current is always equal and opposite to the sum of the other two, thus making the resultant current zero and rendering a fourth return wire unnecessary. Each wire acts alternately to carry the return current for the other two.

(14) It is shown in Art. **21** that in a balanced three-phase system the current flowing in one wire is equal to the sum of the currents flowing in the other two and is in the opposite direction. Also, that when the current in one wire is at its maximum value, the currents in the other two are one-half as large and in the opposite direction. It follows, then, that if the current in one wire is at its maximum value of 100 amperes and is flowing *out*, the currents in the other two wires must be 50 amperes and flowing *in*.

(15) (*a*) The maximum value is the highest value reached during each half wave or alternation.

(*b*) The average value is the average of all the values of current or E. M. F. that are passed through during a half cycle.

(*c*) The average value is .636 times the maximum value, or a little less than two-thirds the maximum. See Art. **24.**

(16) (*a*) The effective value of an alternating current is that value that will produce the same heating effect in the circuit as a continuous current of the same amount. The effective value is often called the square-root-of-mean-square value, because it is equal to the square root of the average of the squares of the values of the current at each instant throughout an alternation.

(*b*) The effective value is .707 times the maximum, or slightly more than seven-tenths of the maximum. See Art. **24.**

(17) (*a*) It means that the effective or square-root-of-mean-square value is 50 amperes and that the alternating current produces the same heating effect as would 50 amperes direct current.

(*b*) Since the effective value (50 amperes) is .707 times the maximum, the maximum value in this case must be $\frac{50}{.707} = 70.7$ amperes, and the current will alternate between the values $+70.7$ amperes and -70.7 amperes.

(*c*) The average value is .636 times the maximum, or $.636 \times 70.7 = 45$ amperes, approximately, or we may get the same result by dividing the effective value (50 amperes) by 1.11, i. e., $\frac{50}{1.11} = 45$, approximately. See Art. **25.**

(18) (*a*) The E. M. F. of self-induction is set up in a coil or circuit by reason of the changing magnetic field threading the coil or circuit, this changing field being set up by a changing current flowing in the coil, circuit, or whatever electrical device is under consideration.

(*b*) No, because the current is steady and, hence, no changing field can be set up to induce the E. M. F. In order that an E. M. F. may be set up, the magnetic field and the coil or circuit must be continually changing relatively to each other. See Arts. **27** and **28.**

(19) (*a*) The coefficient of self-induction of any electrical circuit or device is a quantity that is a measure of the ability that the circuit or device has for setting up lines of force through itself when a current is sent through it. If the coefficient of self-induction is high, it means that a small current is capable of setting up a large number of lines of force, and *vice versa*. The coefficient of self-induction is defined in Art. **30**; it is equal to the number of lines threading the circuit or coil, when a current of 1 ampere is flowing, multiplied by the number of turns and divided by 10^8.

(*b*) The henry is the unit used to express inductance.

(*c*) Yes, because the coil when wound on the iron core would be able to set up a much larger magnetic flux through itself than when wound on a wooden core.

(20). It makes the current lag behind the E. M. F., so that the current does not reach its maximum value until after the E. M. F. has passed its maximum value. See Art. **26.**

(21) (*a*) The induced E. M. F. is at right angles to the current, and when the current is a maximum the induced E. M. F. is passing through zero, and *vice versa.* Also, the induced E. M. F., or E. M. F. of self-induction, is 90° *behind* the current in phase.

(*b*) The E. M. F. *to overcome* self-induction is the equal and opposite of the E. M. F. of self-induction; hence, it is 90° *ahead* of the current in phase. See Art. **33.**

(22) From formula **2,** we have: Induced E. M. F. $= 6.283\, n\, L\, C = 6.283 \times 60 \times .02 \times 5 = 37.7$ volts, nearly. Ans.

(23) From Art. **35** and Fig. 25 we see that the applied E. M. F. is equal to the square root of the sum of the squares of the induced E. M. F. and the E. M. F. necessary to overcome resistance, because in Fig. 25, $o\,c =$ applied E. M. F. and $o\,c^2 = o\,b^2 + b\,c^2$, or

$$o\,c = \sqrt{o\,b^2 + b\,c^2}.$$

In this case $o\,b$ is 8 volts and $b\,c$ is 20 volts; hence,

Applied E. M. F. $= \sqrt{8^2 + 20^2} = \sqrt{464} = 21.54$ volts. Ans.

(24) (*a*) The reactance of a circuit is that quantity which multiplied by the current gives the E. M. F. necessary to force the current against the self-induction of the circuit.

(*b*) The value of the reactance is given by the product $6.283\, n\, L$, where n is the frequency in cycles per second and L the coefficient of self-induction.

(*c*) Reactance, like resistance, is expressed in ohms. See Art. **38.**

(25) (*a*) The impedance of a circuit is that quantity by which the current must be multiplied to give the applied, or impressed, E. M. F. necessary to force the current through the circuit.

(*b*) The impedance is equal to the square root of the sum of the squares of the resistance and reactance; i. e., $\sqrt{R^2 + (6.283\, n\, L)^2}$.

(*c*) Impedance, like resistance and reactance, is expressed in ohms. See Art. **39.**

(26) $C = \frac{E}{\sqrt{R^2 + (6.283\, n\, L)^2}}$, or current $= \frac{\text{applied E. M. F.}}{\text{impedance}}$. See Art. **36.**

(27) (*a*) The reactance is equal to $6.283\, n\, L = 6.283 \times 60 \times .1 = 37.7$ ohms, nearly. Ans.

(*b*) Impedance $= \sqrt{\text{resistance}^2 + \text{reactance}^2} = \sqrt{20^2 + 37.7^2} = \sqrt{1821.3} = 42.7$ ohms, approximately. Ans.

(*c*) The current $= \frac{\text{applied E. M. F.}}{\text{impedance}} = \frac{1,000}{42.7} = 23.4$ amperes. Ans.

(*d*) If the circuit had no self-induction, the reactance would become zero (see Art. **36**); hence, we would have

$$\text{Current} = \frac{E}{\sqrt{R^2}} = \frac{1,000}{20} = 50 \text{ amperes. Ans.}$$

It is thus seen that with the given applied E. M. F. of 1,000 volts, the effect of the self-induction is to cut down the current from 50 amperes to 23.4 amperes.

(28) It has exactly the opposite effect to self-induction; i. e., it makes the current lead the E. M. F. instead of lag behind it.

(29) The power expended in watts cannot be obtained under such circumstances because the current and E. M. F. are not in phase and there are intervals during each cycle when the current and E. M. F. are opposing each other, so

that the actual power in watts is less than would be found by multiplying the volts by the amperes. See Art. **49.**

(30) (*a*) The power factor is the quantity by which the volt-amperes or apparent watts must be multiplied to give the number of actual watts expended. Or it may be defined as the ratio of the actual watts or true watts to the apparent watts.

(*b*) The value of the power factor for direct-current circuits or for non-inductive, alternating-current circuits, is 1. See Arts. **50** and **51.**

(31) Apparent watts $= 50 \times 100 = 5{,}000$; power factor $= \dfrac{\text{true watts}}{\text{apparent watts}} = \dfrac{4{,}200}{5{,}000} = .84$. Ans. See Arts. **50** and **51.**

ALTERNATING CURRENTS

(PART 2.)

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(1) (*a*) A squirrel-cage armature consists of a number of copper bars placed in slots arranged around the periphery of a laminated core. These bars are all connected together at each end by means of rings, thus forming the bars into a number of closed circuits. See Fig. 29.

(*b*) The revolving field set up by the field windings cuts across the conductors, thus inducing E. M. F.'s that are able to set up currents because the bars are formed into closed circuits.

(2) To prevent a heavy rush of current in the armature and field. If a heavy rush of current is allowed in the armature it reacts on the field so as to greatly reduce the field strength and bring the starting torque down to a small amount. Besides, the heavy rush of current affects other motors or lights on the system, and is therefore objectionable See Art. **48.**

(3) (*a*) An inductor alternator is one in which the E. M. F. is set up in stationary armature coils by varying the magnetic flux passing through them by means of revolving masses of iron.

(*b*) No; the magnetic flux can be set up by means of a stationary coil surrounding the inductor, and as the armature coils are also stationary, no moving wire or sliding contacts are required.

(4) The armature is provided with three groups of coils that are displaced relatively to each other on the armature core so that the currents generated in them differ in phase by the required amount. The coils may be displaced a distance equivalent to 120° of the phase difference, i. e., one-third the distance from the center to center of poles of like polarity, or they may be displaced by a distance giving a phase difference of 60°, i. e., one-sixth the distance from the center to center of poles of like polarity. In the latter case, one of the phases is reversed in order to give three currents differing in phase by 120° instead of three differing in phase by 60°. This latter method of winding is very generally used because it is somewhat easier to carry out mechanically than the first. See Art. **18.**

(5) (*a*) In the core transformer the coils are wound around the core, and thus cover the core to a large extent, while in the shell transformer the iron magnetic circuit is arranged so that it covers the larger part of the coils. See Figs. 21, 22, 23, and 24.

(*b*) In order to avoid magnetic leakage. If the coils are interleaved, there is not the chance for magnetic flux to leak between them that there is when they are separated. See Arts. **30** and **31.**

(6) The relation between the voltage of each phase and the direct-current voltage is the same for the two-phase converter as for the single-phase. See Art. **52.** Applying formula **3,** we have

$$E = .707\ V;$$
$$350 = .707\ V;$$
or
$$V = \frac{350}{.707} = 495 \text{ volts. Ans.}$$

(7) (*a*) The speed falls off slightly with an increase in load, but the speed regulation as a whole is fully as good as that of a shunt-wound direct-current motor.

(*b*) The slip is the difference in speed between the revolving armature and the revolving field. It is usually

expressed as a percentage of the speed at which the motor would run when in synchronism with the alternator. See Art. **47.**

(8) (*a*) The ratio of transformation is the ratio of the primary voltage to the secondary voltage at no load or it is the ratio of the number of primary turns to the number of secondary turns.

(*b*) The ratio of transformation is $\frac{600}{60} = 10$; hence the secondary voltage will be $\frac{2200}{10} = 220$. Ans. See Art. **26.**

(9) (*a*) A transformer consists essentially of three parts, namely, the primary coil or group of coils, the secondary coil or group of coils, and the laminated core. The coils are wound around the core, and the purpose of the core is to carry the magnetic flux (set up by the primary) through the secondary.

(*b*) No; because there is always some loss in the transformer.

(*c*) The copper loss, or loss due to the resistance of the coils; the loss due to eddy currents set up in the iron core; the loss due to hysteresis in the iron caused by the rapid reversals of the magnetism. See Art. **28.**

(10) From formula **1**, we have

$$n = \frac{p}{2} \times s;$$

where p = number of poles and s = revolutions per second, hence

$$n = \frac{16}{2} \times \frac{450}{60} = 60 \text{ cycles per second. Ans.}$$

(11) The resistance of the primary and secondary coils, also magnetic leakage. Part of the E. M. F. is required to overcome the resistance of the coils; the drop in the primary lessens the E. M. F., which divided by the ratio of transformation gives the secondary E. M. F. The effect of the resistance of the secondary is, of course, to cut down the E. M. F. at the terminals of the secondary. The magnetic

leakage lowers the secondary E. M. F. because it reduces the number of lines of force that thread through the secondary. See Art. **27.**

(12) Using formula **4,** we have

$$E = .612\ V;$$
$$E = .612 \times 110 = 67.3 \text{ volts.} \quad \text{Ans.}$$

(13) Because the current in the armature is induced by the magnetism set up by the currents in the field instead of being led into the armature from an outside source, as in ordinary motors.

(14) The two methods are the **Y** or star connection and the Δ (delta) or mesh connection. In the former, one end of each group is connected to a common junction and the other three ends are attached to the collector rings. In the Δ method the three groups are connected so as to form a closed circuit, and the collector rings are attached to the junctions of the groups. See Art. **20.**

(15) (*a*) The distance between the centers of the poles.

(*b*) Because there would be danger of opposing E. M. F.'s being set up in the two sides of the coil. See Art. **8.**

(16) The speed s in revolutions per second is $\frac{250}{60}$; hence, applying formula **2,** we have

$$\frac{250}{60} = \frac{2 \times 25}{p}, \text{ or } p = \frac{2 \times 25 \times 60}{250} = 12.$$

p is the number of poles; hence, the number of poles required will be 12. Ans.

(17) (*a*) A synchronous motor is an alternating-current motor that runs in synchronism with the alternator that supplies it with current. See Art. **38.**

(*b*) They are practically the same in construction as the alternator of the same type. Synchronous motors, like alternators, may be built with either a revolving armature or revolving field.

(*c*) Because the armature is subjected to a rapidly reversing torque and the turning effort in one direction is followed by another in the opposite direction before the armature gets started. See Art. **39.**

(18) The speed will be such that $s = \frac{2n}{p}$, when n is the frequency and p the number of poles, or $s = \frac{2 \times 25}{10} = 5$ revolutions per second, or 300 R. P. M. Ans. See Art. **42.**

(19) Because they give a larger number of conductors in series between the collector rings than closed-circuit windings having the same number of armature conductors, and, hence, are well adapted to the generation of the high voltages that are generally required in connection with alternating-current systems. See Art. **5.**

(20) No; because the motor must run at the same frequency as the alternator, and the only thing that can change the speed of the motor is a change in the speed of the alternator driving it. Changing the field excitation of a synchronous motor will, however, change the current that the motor takes when carrying a given load, and the field excitation should always be adjusted so that the motor takes the minimum current.

(21) When the motor is running without load, the E. M. F. of the motor is almost exactly opposite in phase to that of the dynamo, but as the load is applied, the motor lags a small fraction of a revolution, thus displacing its E. M. F. with regard to that of the alternator, so that it is not so nearly opposed to it. This allows more current to flow through the motor and enables it to carry its load. See Art. **40.**

(22) (*a*) A monocyclic alternator is a single-phase machine provided with an auxiliary winding that is displaced 90° from the main winding. This auxiliary winding has about one-quarter as many turns as the main winding and is intended to supply a displaced current for use in

starting motors. One end of the auxiliary winding is connected to the middle point of the main winding and the other end is carried to the middle collector ring.

(*b*) The monocyclic machine is intended for those places where the load consists principally of lights, but where it may be desired to operate a few motors also.

(*c*) The pressure between the middle and outside rings is about .56 times the pressure generated in the main winding, or $.56 \times 2{,}200 = 1{,}232$ volts. Ans.

(23) The armature is provided with two windings or groups of coils that are displaced from each other, so that when the current in one group of coils is at its maximum value, the current in the other group is at zero. See Arts. **17** and **57.**

(24) (*a*) The rectifier is used to make the current that flows through the series field coils always flow in the same direction.

(*b*) No; because the rectifier simply changes the connections of the terminals of the series coil as the current alternates, so that, although the current in the series coils does not reverse, the current in the mains is alternating. See Art. **13.**

(25) From formula **4** we have

$$E = .612\ V;$$

or,

$$200 = .612\ V;$$

and

$$V = 326.8. \quad \text{Ans.}$$

ELECTRIC TRANSMISSION.

(PART 1.)

---

(1) (*a*) An ampere-hour meter is a device that gives the sum of the products obtained by multiplying each current value by its own duration in hours.

(*b*) No; because the power factor is not taken into account and the current might be much larger in proportion to the actual watts or power supplied than it would be if the load were non-inductive. See Art. **102.**

(2) Because if a short circuit should occur in the primary or secondary coils, there would be a heavy rush of current and the coils would be burned out if the transformer were not at once disconnected from the circuit. Also, the fuses protect the transformer against overloads. See Art. **71.**

(3) (*a*) The connections would be similar to those shown in Fig. 37.

(*b*) Care should be taken to see that the current coil and pressure coil are not confused, because if the low-resistance current coil were connected across the circuit, a short circuit would result. See Art. **94.**

(4) 100 horsepower $= 100 \times 746 = 74{,}600$ watts,

hence $$\text{Current} = \frac{74{,}600}{500} = 149.2 \text{ amperes.}$$

The length of wire is 5 miles, or $5 \times 5{,}280 = 26{,}400$ feet.

Applying formula **10**, we have

Circular mils $= \frac{10.8 \times 26{,}400 \times 149.2}{50} = 850{,}800$ approximately.

This would call for a stranded cable or about 4 No. 0000 wires in multiple.

(5) It is easily seen from the figures that the meter has run up to its limit (10,000,000) and has started over again. Hence, the watt-hours will be $(10{,}000{,}000 - 9{,}995{,}400)2 + (230{,}200)2 = 469{,}600$ watt-hours, or 469.6 kilowatt-hours. Hence, amount of bill would be

$$469.6 \times .05 = \$23.48. \quad \text{Ans.}$$

(6) (*a*) Since 30,000 watts are delivered and since the pressure at the end of the line is 500, the current must be

$$C = \frac{W}{E} = \frac{30{,}000}{500} = 60 \text{ amperes.} \quad \text{Ans.}$$

(*b*) Since the station voltage is 525 and the voltage at the distant end of the line is 500, the drop or loss in pressure must be equal to $525 - 500 = 25$ volts. Ans.

(*c*) The watts lost in the line will be equal to the current multiplied by the volts drop; hence,

$$\text{Watts lost} = 60 \times 25 = 1{,}500,$$

and since 1 horsepower = 746 watts, we have

$$\text{Horsepower lost in line} = \frac{1{,}500}{746} = 2.01. \quad \text{Ans.}$$

(*d*) The watts supplied must be equal to the watts delivered plus the watts lost; hence, watts delivered to the line $= 30{,}000 + 1{,}500 = 31{,}500$, and the horsepower delivered to the line $= \frac{31{,}500}{746} = 42.2$. Ans.

(7) (*a*) Starting with the dial at the extreme right, we note that the hand is about $\frac{7}{10}$ of the way between *6* and *7*; hence, the reading is 670; but 700 would probably be taken, as it is hardly worth while to take the reading closer than

the nearest hundred. The second hand has not completed the division from *0* to *1*, hence we have the reading 0700; the third hand has completed a little over nine divisions, hence we have 90,700. The fourth hand has not completed quite four divisions, and the fifth hand has not completed one division, hence we have the complete reading 390,700.

(*b*) $390{,}700 - 300{,}400 = 90{,}300$; and since the constant is $\frac{1}{2}$, the actual watt-hours will be $90{,}300 \times \frac{1}{2} = 45{,}150$. Ans.

(8) (*a*) Direct current is usually employed where the distance of transmission is short or in cases where high pressures are not necessary.

(*b*) Alternating current is used in cases where the power must be transmitted over a considerable distance and where high pressures must be used. Alternating current at low pressure is also used in many short-distance transmissions, as, for example, in factories. See Art. **3.**

(9) (*a*) The meter will not operate even if the magnets are swung in as far as they will go.

(*b*) The meter will run much above its correct speed and there is danger of the armature being burned out.

(*c*) No; because these meters depend on induced currents for their operation, and a continuous current cannot set up the changing magnetic field necessary to induce the currents in the armature of the meter. See Arts. **118** and **101.**

(10) (*a*) $\frac{630}{650} = .969$, or 96.9 per cent. of the actual energy was recorded by the meter; hence the meter was 3.1 per cent. too slow.

(*b*) The trouble could be remedied by shifting the permanent magnets in a little.

(11) By using formula **9,** we can calculate the resistance because both the length and cross-section of the wire are known. In order to use the formula, the length L must be expressed in feet, hence $L = 5{,}280 \times 3 = 15{,}840$ feet, and $R = \frac{10.8 \times L}{A} = \frac{10.8 \times 15{,}840}{26{,}000}$ or 6.58 ohms, nearly. See Art. **44.**

(12) (*a*) The connections should be similar to those shown in Fig. 31 (*c*).

(*b*) Since both the primary and secondary are connected Δ, the voltage applied to each primary coil will be 1,100, and the voltage between the secondary mains will be $\frac{1100}{10} = 110$ volts. Ans.

(13) (*a*) The "drop" is the loss or falling off in pressure that occurs between the power station and the distant end of the line.

(*b*) The drop depends on the resistance of the line and the amount of current transmitted over the line. The drop in volts is equal to the current in amperes multiplied by the line resistance expressed in ohms. The drop, therefore, increases as the load on the line increases. See Arts. **36** and **37.**

(14) (*a*) To find the full-load current, we will use formula **15.** Since the load consists of motors and lights, and since the three-phase system is to be used, the constant T will be .679. $W = 500{,}000$ watts, because 500 kilowatts are to be transmitted. $E_2 = 10{,}000$; hence,

$$\text{Current} = \frac{W}{E_2} \times T = \frac{500{,}000}{10{,}000} \times .679 = 33.95 \text{ amperes. Ans.}$$

(*b*) The size of wire in circular mils may be obtained by using formula **14,**

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t.$$

In this case, $D = 10$ miles $= 52{,}800$ feet;
$W = 500{,}000$;
$P = 10$;
$E_2 = 10{,}000$;
$t = 1{,}500$.

Hence, circular mils $= \dfrac{52{,}800 \times 500{,}000}{10 \times 100{,}000{,}000} \times 1{,}500 = 39{,}600$, or about a No. 4 B. & S. Ans.

(*c*) To calculate the drop, we may use formula **16.**

Or, $$\text{Drop} = \frac{P \times E_2}{100} \times M,$$

where $P = 10$; $E_2 = 10{,}000$; and M for this case is equal to 1.

Hence, $$\text{Drop} = \frac{10 \times 10{,}000}{100} = 1{,}000 \text{ volts.} \quad \text{Ans.}$$

(15) The diameter of the wire is .016 inch, or 16 mils, and since the area of cross-section in circular mils is equal to the square of the diameter expressed in mils, we have area of cross-section in circular mils $= 16^2 = 256$. Ans.

(16) (*a*) An indicating wattmeter is an instrument that indicates the watts expended in a circuit at any given instant. Its reading indicates the actual watts expended at the time the reading is taken; that is, it gives the product of the volts and amperes when used with direct current or with alternating current on a non-inductive circuit. If used on an inductive alternating-current circuit, the indicating wattmeter indicates the actual watts expended or the product of the volt-amperes by the power factor. See Art. **93.**

(*b*) A recording wattmeter is an instrument for recording the total amount of work done during a given time. The indicating wattmeter is a *power* indicator; or, in other words, it indicates the rate at which work is being done, whereas the recording wattmeter indicates the total amount of *work done* or *energy expended* in a given time.

(*c*) A recording wattmeter usually registers watt-hours or else gives a reading that, multiplied by a constant, gives the watt-hours expended.

(17) Alternating-current dynamos can be readily built to generate high pressures, because there is no commutator to give trouble. Also, alternating current can be easily transformed from one pressure to another, so that the current can be transmitted at high pressure and then lowered for use in

connection with lighting, the operation of motors, or any other purpose where high pressures would be objectionable. See Arts. **60** and **61.**

(18) From formula **20,** we have

$$\text{Watts} = \frac{R \times K \times 3{,}600}{T}.$$

In this case, $T = 80$ seconds, $R = 15$, $K = 2$.

Hence, $\text{watts} = \dfrac{15 \times 2 \times 3{,}600}{80} = 1{,}350.$ Ans.

(19) (*a*) A mil is the thousandth part of an inch, i. e., 1 mil = .001 inch.

(*b*) A circular mil is a unit of area used for comparing and expressing the area of cross-section of wires. It is the area bounded by a circle the diameter of which is 1 mil or one-thousandth of an inch, and it is therefore equal to .0000007854 square inch. See Arts. **21, 22,** and **23.**

(20) This problem can be solved by using formula **19,** 25 horsepower = 25 × 746 = 18,650 watts. Hence, we have $18{,}650 = 1.732 \times 500 \times C \times .80$.

Hence,

$$C = \frac{18{,}650}{1.732 \times 500 \times .80} = 26.9 \text{ amperes.} \quad \text{Ans.}$$

(21) (*a*) Because the single-phase system is not well adapted for the operation of alternating-current motors.

(*b*) For lighting work. See Arts. **62** and **63.**

(22) Yes; because when they are strung far apart there is a greater area between them for magnetism to thread through; hence, there will be a larger magnetic flux to cut the lines. See Art. **85.**

(23) No; the connections could not be made in this way, because the E. M. F.'s set up in the secondaries would be out of phase with each other and the transformers would send current around through each other's secondary coils.

(24) Because these systems allow the operation of alternating-current motors, which are self-starting and which can be constructed so as to start up under load if necessary.

(25) Because it is difficult to build direct-current dynamos and motors for the generation and utilization of current at high pressure, chiefly on account of troubles that arise in connection with the commutator. See Arts. **58** and **59.**

(26) (*a*) The transformers would be connected as shown in Fig. 31 (*d*).

(*b*) No; because if one transformer breaks down, the service is crippled, whereas with three transformers the remaining two will continue to supply current even if one transformer does break down. Of course, if the three transformers were connected **Y** instead of Δ, a breakdown would cripple the service, and this is one of the reasons why the Δ connection is usually preferred.

(*c*) Three transformers of 15 kilowatts each would be sufficient. See Table VIII.

(27) See Art. **51.** Other conditions being equal, the size of the wire will be one-quarter as great, because the voltage has been doubled. The cross-section of No. 0000 is 211,600; hence, the cross-section of the required wire will be $\frac{211,600}{4}$ $= 52,900$, or a No. 3 B. & S., very nearly.

(28) Because all the transformers may not regulate the same with changes in load, with the result that some of the transformers may become overloaded and blow their fuses, thus throwing an additional load upon the remaining transformers and blowing their fuses also. See Art. **75.**

(29) It allows double the voltage to be used and, hence, effects a saving in copper. See Art. **52.**

(30) (*a*) Double- or triple-braid weather-proof wire for the smaller sizes and weather-proof covered cable for the larger sizes.

(*b*) Lead-covered wire or cable insulated with paper or rubber. See Art. **19.**

(31) (*a*) Make a sketch similar to Fig. 28.

(*b*) Connect a pair of lamps in series across the outside lines. They should burn up to full brightness. See Art. **78.**

(32) (*a*) Make a sketch similar to Fig. 22, Art. **74.**

(*b*) Care must be taken to see that terminals of the same polarity are connected together. Similar terminals of the primary should be connected to the same mains, and terminals of the secondary having like polarity should be connected together, or a short circuit will result. See Art. **74.**

ELECTRIC TRANSMISSION.

(PART 2.)

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(1) (*a*) About 1,000 circular mils per ampere.

(*b*) About 1,500 circular mils per ampere. See Art. **95.**

(2) (*a*) 22 inches in circumference or 7 inches in diameter.

(*b*) For ordinary lines, 40 poles to the mile should be sufficient; for heavy lines, 52 poles per mile should be used. See Arts. **3** and **5.**

(3) Porcelain insulators are not as likely to crack as glass when subjected to mechanical shocks. They maintain a higher insulation during rain storms, but their insulation is not as high as that of glass during dry weather. Also, porcelain insulators are more likely to have cocoons and cobwebs formed inside of them on account of the interior being dark. See Art. **8.**

(4) A deep-groove double-petticoat glass insulator similar to that shown in Fig. 4, Art. **9.**

(5) The conductors are placed in iron pipes that are filled with insulating compound. The tubes are buried directly in the ground and are not placed in ducts of any kind. The conductors are, therefore, not removable as in conduit systems. The lengths of tube are joined together by means of coupling boxes, which are filled with insulating compound after the conductors have been joined by means of flexible copper connections. See Art. **29.**

(6) So as to prevent the accumulation of gas that is likely to lead to an explosion. See Art. **21.**

(7) The two machines must be brought to the same voltage, and they must also be brought into synchronism; that is, they must be running at the same frequency and must also be in phase. Equality of frequency is the most important requirement.

(8) From formula **1,** we have

$$R = \frac{(V - V_1)\,r}{V_1}.$$

In this case, $V = 120$, $V_1 = 5$, and $r = 17{,}000$;

hence, $R = \frac{(120 - 5)\ 17{,}000}{5} = 391{,}000$ ohms. Ans.

(9) The length of the loop formed by joining the far end will be 24,000 feet; hence,

$$R = 24 \times .123 = 2.952 \text{ ohms},$$

and $$x = \frac{1{,}000 \times 2.952 - 10 \times 162}{1{,}000 + 10} = 1.319.$$

Hence, the distance of the fault from the testing station must be $\frac{1.319}{.123} \times 1{,}000 = 10{,}724$ ft. Ans.

(10) Either by means of synchronizing lamps or a synchronizing voltmeter. Synchronizing lamps constitute the simplest method and the one most commonly used. The connections of these lamps may be made so that when the machines are in phase the lamps burn up to full brightness, or the connections may be such that the lamps indicate synchronism when they are dark. The connections for the lamps are described in Art. **91.**

(11) See Art. **42;** also Figs. 39 and 40.

(12) (*a*) They should be placed on the line as well as in the station, because it is better to allow the discharge to pass off before reaching the station than to depend on the station arresters alone.

(*b*) No; it merely diverts the discharge by providing a path for it to pass off to the ground. See Arts. **44** and **45.**

(13) Because if a discharge comes in over both lines at once, a short circuit takes place between the gaps of the arrester, and a heavy rush of current would follow if the arc were not immediately extinguished.

(14) Alternators cannot be run in series unless they are rigidly connected together on the same shaft. If the machines were driven separately, their operation would be unstable. See Art. **76.**

(15) (*a*) Yes.

(*b*) Yes; it should connect the two points at which the brushes connect to the series coils. See Art. **85.**

(16) (*a*) No; not unless the field rheostats of the machines were continually regulated, and this would be hardly practicable if the load were a fluctuating one.

(*b*) Either provide the shunt machine with a series winding and run both as compound-wound machines or else cut out the series coils on the compound-wound machine and run both as shunt machines. The first method would probably be the better, because the compound-wound machines would maintain better voltage regulation. See Art. **88.**

(17) Because the discharge is oscillatory, and, on account of the high frequency at which it alternates, a high counter E. M. F. is set up in the inductive path.

(18) To interpose an inductive path between the line and the dynamo, and thus force the discharge to leap across the air gap of the lightning arrester. The kicking coil must always be connected between the device to be protected and the lightning arrester. See Art. **46.**

(19) No; because as soon as the machines are put in multiple, their series shunts are also in multiple, and any change in either shunt affects both machines. The adjustment should be made by inserting a small amount of resistance in series with the series field coil of the machine

showing the smaller drop through its series field. See Art. **86.**

(20) The full-load current of the large machine multiplied by the resistance of its series coil and switchboard lead must be equal to the full-load current of the small machine multiplied by the resistance of its field coil and switchboard lead. In other words, the drop through the two parts *a b* and *c d*, Fig. 63, must be equal. See Art. **86.**

(21) Yes; because the voltage of a shunt machine drops slightly with increase in load, and this tends to equalize the load between the machines. See Art. **82.**

(22) (*a*) Because if the load on one of the machines decreases, its voltage falls still lower because its field excitation decreases. See Art. **78.**

(*b*) By adding an equalizing connection so as to connect the fields of the machines in parallel. This wire connects the two brushes to which the fields are attached.

(23) (*a*) From 2 to 2.5 volts.

(*b*) From 2.2 to 1.8 volts.

(*c*) 1.8 volts. See Arts. **60** and **68.**

(24) No; the charging current forms certain chemical compounds that, when the cell is discharged, change back to their original form and in doing so set up a current.

(25) (*a*) The capacity is usually given in ampere-hours, i. e., the product of the normal discharge rate by the number of hours that the battery can maintain the discharge.

(*b*) Yes; a high rate of discharge decreases the output, and if carried too far may result in buckled plates. See Art. **59.**

(26) (*a*) The true efficiency is the watt-hour efficiency, because this gives the ratio of the total energy delivered to the total energy supplied. It is obtained by dividing the number of watt-hours delivered when the battery is discharged by the number of watt-hours supplied when the battery is charged.

(*b*) The ampere-hour efficiency is the ratio of the number of ampere-hours delivered to the number of ampere-hours supplied.

(*c*) Because the voltage required for charging is considerably higher than the voltage obtained at discharge, and moreover the voltage of the cells falls off as they become discharged. See Art. **59.**

(27) (*a*) Lead peroxide.

(*b*) Spongy lead.

(*c*) Both change to lead sulphate. See Art. **56.**

(28) The plate at which the current flows in when the cell is charging and out when it is discharging. See Art. **55.**

(29) In the Planté plate the active material is formed on the lead plate itself either by chemical treatment or by repeated charging and discharging. In the Faure, or pasted, plate the active material is applied in the form of a paste and is held in grooves or openings provided for the purpose. See Arts. **57** and **58.**

ELECTRIC LIGHTING.

(PART 1.)

(1) See Art. **70.**

(2) (*a*) A sketch similar to that shown in Fig. 32 is required.

(*b*) The large transformers are more efficient, and a few large transformers are easier to look after and to keep in repair than a number of small ones. See Art. **65.**

(3) (*a*) In parallel. See Art. **46.**

(*b*) In multiple series, two in series on 220 volts and five in series on 500 volts. See Art. **48.**

(4) See Arts. **55** and **56.**

(5) (*a*) The filament, the bulb, the leading-in wires, and the base.

(*b*) Carbon; usually the carbon is made by carbonizing a squirted cellulose thread.

(*c*) Platinum; because it does not oxidize and also because it has very nearly the same coefficient of expansion as glass.

(6) (*a*) The Edison, Thomson-Houston, and Westinghouse.

(*b*) The Edison. See Arts. **15** and **16.**

(7) (*a*) The standard candle.

(*b*) 1 candle = 1.14 Hefner units. See Art. **19.**

(8) (*a*) A photometer is an instrument for comparing the candlepower of two sources of light and for measuring the candlepower of a source by comparing it with a standard whose candlepower is known. See Art. **20.**

(*b*) See Art. **24.**

(9) In this case, the distance of the standard from the screen is 350 divisions; hence, from formula **2,** $d_1 = 350$. The distance of the lamp from the screen is $500 - 350 = 150 = d_2$; hence, the candlepower of the lamp test is, from formula **2,**

$$I = 32\frac{150^2}{350^2} = 5.88 \text{ c. p.} \quad \text{Ans.}$$

(10) (*a*) The mean horizontal candlepower is the average of the light intensities given out by the lamp in all directions in the horizontal plane.

(*b*) It is usually determined by spinning the lamp about a vertical axis while the measurement is being made on the photometer. See Art. **28.**

(11) (*a*) From 1,250° to 1,350° C.

(*b*) About 3.33 watts per candlepower. See Arts. **32** and **33.**

(12) See Art. **36.** Applying the rule there given, we have

$$\text{Number of lamps} = \frac{30 \times 1{,}000}{60} = 500. \quad \text{Ans.}$$

(13) (*a*) A system in which the current is carried from the station to centers of distribution by means of feeders, which are not tapped at any intermediate point. From the distributing centers the current is supplied to the customers by means of distributing mains. See Art. **51.**

(*b*) Since lamps are not tapped off the feeders at intermediate points, a large drop may be allowed in the feeders

without causing large variations in the lamp voltage. Also, it allows the different sections of the system to be readily controlled from the station. See Art. **52.**

(14) See Art. **75** and Fig. 41.

(15) (*a*) Total current in feeders $= \frac{300}{2} + \frac{200}{2} + \frac{150}{2}$ $= 325$ amperes, since each lamp requires $\frac{1}{2}$ ampere. Total drop $= 12$ volts; drop in mains $= 3.5$ volts; drop in house wiring $= 1.5$ volts; total drop in mains and house wiring $= 5$ volts; drop in feeders $= 12 - 5 = 7$ volts. The size of the various feeders may be calculated by using formula **5.** For the main feeders we have

$$A = \frac{21.6 \times 325 \times 250}{7} = 250{,}714 \text{ cir. mils. Ans.}$$

(*b*) Current in mains D is 150 amperes and distance is 300 feet.

Hence,

$$A = \frac{21.6 \times 150 \times 300}{3.5} = 277{,}714 \text{ cir. mils. Ans.}$$

(*c*) Current in $E = 75$ amperes; distance $= 400$ feet.

Hence,

$$A = \frac{21.6 \times 75 \times 400}{3.5} = 185{,}143 \text{ cir. mils. Ans.}$$

(*d*) Current in $F = 100$ amperes; distance $= 200$ feet.

Hence,

$$A = \frac{21.6 \times 100 \times 200}{3.5} = 123{,}428 \text{ cir. mils. Ans.}$$

(16) We will call I the brightness of the source of light and x_1 the degree of illumination of the object when it is placed 10 feet from the source. Then, from formula **1,**

$$x_1 = \frac{I}{10^2}.$$

Also, if x_2 represents the degree of illumination in the second position, we have

$$x_2 = \frac{I}{35^2}.$$

Hence, we have

$$\frac{x_1}{x_2} = \frac{\frac{I}{100}}{\frac{I}{1,225}}.$$

$$\frac{x_1}{x_2} = \frac{1,225}{100}.$$

$$x_1 = 12.25\, x_2.$$

That is, the illumination at a distance of 10 feet is 12.25 times as great as that at 35 feet, or the illumination is reduced 12.25 times. See Art. **21.**

(17) See Art. **27.**

(18) (*a*) The hot resistance is much less than the cold resistance, because the resistance of carbon decreases as the temperature increases.

(*b*) About 220 ohms. See latter part of Art. **35.**

(19) See Art. **35.** The current required for each lamp will be equal to $\frac{32 \times 4}{220}$, and for 160 lamps it will be $\frac{32 \times 4 \times 160}{220} = 93.09$ amperes. Ans.

(20) (*a*) The candlepower that the lamp gives in the several directions reduced to what the candlepower would be if the light were given out uniformly in all directions. See Art. **30.**

(*b*) No; the mean horizontal candlepower is generally used.

(21) The booster must generate 25 volts and carry 500 amperes; hence, its capacity will be $25 \times 500 = 12,500$ watts, or 12.5 K. W. Ans.

(22) See Fig. 30. The sketch required will be somewhat similar to Fig. 30 except that a two-wire circuit should be shown, and, of course, only one booster will be required.

(23) In working the problem, we will consider the outside wires only and treat it as if it were a two-wire system. The current supplied the lamps E will be 1 ampere for each pair of lamps, because the lamps are 32 candlepower. The current supplied to branch E will, therefore, be 18 amperes. The current supplied to F will be $\frac{300}{4} = 75$ amperes, because these lamps are of 16 candlepower. The total current in the outside wires C will, therefore, be $75 + 18 = 93$ amperes.

(*a*) The drop in each of the feeders C is 5 per cent. of 110, or 5.5 volts, or the total drop for both sides is 11 volts, and by applying formula **5**, we have

$$A = \frac{21.6 \times 93 \times 300}{11} = 54{,}785 \text{ cir. mils. Ans.}$$

(*b*) The mains D carry 75 amperes and the drop on each side is 3 per cent., or 3.3 volts. The total drop in the outside wires is, therefore, 6.6 volts. The distance is 500 feet; hence,

$$A = \frac{21.6 \times 75 \times 500}{6.6} = 122{,}727 \text{ cir. mils. Ans.}$$

(*c*) In this case, the center of distribution is 350 feet from the junction box; hence, the distance to be used in the formula is 350 feet. The current is 18 amperes and the drop is 5 per cent. on each side, or 11 volts between the outside wires.

$$A = \frac{21.6 \times 18 \times 350}{11} = 12{,}371 \text{ cir. mils. Ans.}$$

It will be noticed that the branch feeders and mains D call for a larger wire than the main feeders C, although they carry less current. This is because of the longer length of D and the small drop allowed.

(24) See Arts. **41** and **42**.

(25) See Art. **85.** Total power supplied to lamps $= 3{,}000 \times 16 \times 3.5 = 168{,}000$ watts; power delivered at end of line to primaries of transformers $= 168{,}000 + .05 \times 168{,}000 = 176{,}400$.

Referring to *Electric Transmission*, Part 1, and using the formula

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t,$$

we have t for this case $= 1{,}200$, $P = 10$, $D = 20{,}000$, $W = 176{,}400$, $E_2 = 4{,}000$; hence,

$$\text{Circular mils} = \frac{20{,}000 \times 176{,}400}{10 \times 4{,}000 \times 4{,}000} \times 1{,}200 = 26{,}460 \text{ cir. mils}$$

Therefore, a No. 6 B. & S. wire should be used. Ans.

ELECTRIC LIGHTING.

(PART 2.)

---

(1) See Art. **57.**

(2) See Art. **33.**

(3) Switches, bus-bars, ammeters, voltmeters, circuit-breakers or fuses, rheostats, ground detectors, and lightning arresters. See Art. **1.**

(4) (*a*) To allow the voltage on the individual feeders running from the station to be varied.

(*b*) See Art. **54.**

(5) (*a*) Two rheostats are generally used.

(*b*) One is connected in series with the separately excited field of the alternator and the other in series with the shunt field of the exciter.

(*c*) Yes, if a very fine adjustment is not required and if a single exciter is not used to excite several alternators. See Art. **48.**

(6) (*a*) Make a sketch similar to Fig. 37.

(*b*) See Art. **29** for description.

(7) (*a*) Current transformers are used in connection with alternating-current ammeters when the current to be measured is very large or when it is not desirable to bring the high-pressure lines in contact with the instrument. The use of the transformer avoids the carrying of heavy currents through the ammeter and makes it much easier to construct and connect up.

(*b*) Make a sketch of connections similar to those shown in Fig. 18. See Art. **13.**

(8) (*a*) Make a sketch similar to Fig. **36.** See Art. **28** for description.

(*b*) Because the voltmeter gives a better idea than the lamps as to whether or not the ground is a bad one, or, in other words, a voltmeter gives some idea as to the resistance of the fault.

(9) (*a*) Ordinary knife-blade switches, as shown in Figs. 1, 2, and 3.

(*b*) Quick-break switches, as shown in Figs. 4 and 5, or switches in which the arc is formed in a confined space, as in the Westinghouse switch shown in Fig. 7. Where very high pressures have to be handled, oil switches are often used. See Arts. **2** to **7,** inclusive.

(10) The arc is formed in a confined space and is broken by means of a coil that forces an iron plunger into the tube, thus drawing out the arc. See Art. **35.**

(11) Make a sketch similar to Fig. 39. See the latter part of Art. **31** for description.

(12) The connections would be somewhat similar to those shown in Fig. 52, except that three arresters would be connected in series and the middle cylinder of the middle arrester would be connected to the ground.

(13) Because circuit-breakers are more reliable and can be depended on to open the circuit more promptly than fuses. The blowing point of fuses is very often affected by the way in which they are mounted, currents of air, length of fuse, etc. Circuit-breakers, on the other hand, must be kept clean and in good order if they are to be relied on.

(14) Allowing 1,000 amperes per square inch of cross-section, we have area of cross-section $= \frac{1300}{1000} = 1.3$ square inches. A bar 3 inches wide and $\frac{7}{16}$ inch thick will answer.

(15) Pressure wires are small wires run to the station from the main centers from which the light is distributed.

These wires connect to the voltmeter in the station and the instruments indicate the voltage at the various centers of distribution. The voltmeter requires such a small current that there is practically no drop in the pressure wires. See Art. **16.**

(16) (*a*) One that depends for its action on the repulsion or attraction of bodies carrying static charges of electricity.

(*b*) No; at least the current is not appreciable because the capacity of these instruments is exceedingly small. See Art. **14.**

(17) (*a*) Potential transformers are used to step down the voltage so that an ordinary voltmeter may be used to indicate the line pressure. See Art. **12.**

(*b*) Make a sketch similar to Fig. 16.

(18) See Art. **11.**

(19) An ammeter shunt is a low resistance connected in shunt with the ammeter and in series with the circuit. The greater part of the current flows through the shunt, but a small fixed proportion also flows through the ammeter, and the ammeter scale can be marked to indicate the current in the main circuit. See Art. **10.**

(20) (*a*) Yes; because one must be able to tell at a glance just what load each machine is carrying.

(*b*) No, it is not absolutely necessary, but it is nearly always done in well equipped plants. See Art. **9.**

(21) The ammeter should be connected in the negative side, because part of the current delivered by the armature of the machine may flow through the equalizer, and an ammeter connected in the positive lead would not indicate the true load on the machine. See Art. **44.**

(22) (*a*) Pilot lamps are used to indicate when a machine is "picking up" all right and also to give an approximate indication as to whether or not it is up to the proper voltage.

(*b*) Yes; because they must be connected so as to give an indication before the main switch is thrown in. See Arts. **44** and **45.**

(23) By cutting cells in or out by means of end-cell switches. See Art. **64.**

(24) The arrangement of this board is left as an exercise for the student. Many different arrangements are possible, but one similar to that shown in Figs. 58 and 59 would probably be as convenient as any. A sketch of connections similar to Fig. 59, showing the relative location of the different instruments and switches, is what is required.

(25) (*a*) Compensators are used to make the station voltmeter give indications of the voltage at the receiving end of the line and thus avoid the use of pressure wires. See Art. **17.**

(*b*) See Art. **19.**

ELECTRIC LIGHTING.

(PART 3.)

---

(1) See Art. **107.**

(2) Lightning, defective cut-outs, rocker-arm failing to move properly, lamp burning with an abnormally long arc. See Art. **83.**

(3) The magnet cores of the alternating-current lamp must be laminated, whereas in a direct-current lamp they may be solid. Also, in the alternating-current lamp a choke coil is used to take up the excess voltage, whereas in the direct-current lamp a resistance must be used. See Art. **64.**

(4) (*a*) About $\frac{1}{16}$ inch to $\frac{3}{32}$ inch.

(*b*) About $\frac{3}{64}$ inch. See Art. **82.**

(5) The lamp will overheat and the regulating coil may be burned out because the current will be larger than it should be. The resistance in series with the lamp will be overheated and the enclosing globe may be melted. See Art. **86.**

(6) (*a*) No. 6 or 8 B. & S. weather-proof line wire. No. 6 is generally used, as it does not cost much more than No. 8, has a lower resistance, and makes a stronger and more durable line.

(*b*) Because it makes the location of faults much easier and quicker. See Arts. **87** and **89.**

(7) See Art. **66.**

(8) 6.6 amperes and 70 to 78 volts. See Art. **72.**

(9) See Arts. **41** and **42.**

(10) See Art. **39.**

(11) See Figs. 21 and 22.

(12) (*a*) Because if the carbons should stick or fail to feed, the arc would gradually grow longer and there would be danger of the shunt coils being burned out. Also, there would be danger of the circuit being broken. See Art. **49.**

(*b*) In order to provide a sufficient drop of potential through the lamp so that sufficient current will pass through the series coils to enable the lamp to start up. See Art. **49.**

(13) See Arts. **53** and **54.**

(14) (*a*) By varying the amount of resistance in series with the arc. See Art. **76.**

(*b*) By cutting in or out some of the sections of the choke coil. See Art. **78.**

(15) (*a*) The series system, because it allows the use of a small current at high pressure, thus supplying the scattered lights with but small loss in power.

(*b*) By means of a switch that short-circuits the terminals of the lamp.

(*c*) The voltage must increase as the load, i. e., the number of lamps, is increased.

(*d*) No; the current must remain constant. It is maintained at a constant value by means of an automatic regulator on the dynamo. See Arts. **30** and **31.**

(16) See Arts. **32** and **33.**

(17) (*a*) 450 watts.

(*b*) 300 watts. See Art. **25.**

(18) (*a*) Petroleum-coke or gas-retort carbon.

(*b*) Because the impurities, if present in any considerable quantity, are deposited on the inner globe and obscure the light.

(*c*) Lampblack. See Arts. **16** and **17.**

(19) (*a*) See Figs. 7 to 11, inclusive.

(*b*) See Art. **15.**

(20) (*a*) Because the crater is formed in the positive carbon, and if the upper carbon is not made positive, most of the light will be thrown upwards instead of downwards.

(*b*) By noting which carbon remains hot for the longer time when the current is turned off. The upper or positive carbon should be the hotter. See Art. **14.**

(21) No; the ends of the carbons are nearly flat, due largely to the shifting of the arc over the ends. See Art. **12.**

(22) About 6.6 amperes for lamps giving 1,200 nominal candlepower, and 9.6 amperes for lamps of 2,000 nominal candlepower. See Art. **7.**

(23) (*a*) One in which the arc is surrounded by an enclosing globe that, to a large extent, excludes the air from the arc.

(*b*) The consumption of carbon is very much less. An enclosed-arc lamp can easily burn from 100 to 150 hours without retrimming, whereas an open arc can burn about 10 hours only.

(*c*) See Art. **8.**

(24) The carbon points become heated to a very high degree and become pointed. The positive carbon becomes hotter than the negative and burns away about twice as fast. The positive carbon has a crater formed in the end and the greater part of the light is emitted from this crater. See Arts. **3** and **4.**

(25) **(*a*) About 3,500° C.**

(*b*) No.

(*c*) The effect of increasing the current is to increase the size of the crater and thus make the arc give a greater amount of light. The temperature of the arc is, however, not increased. See Art. **5.**

(26) (*a*) About 45° below the horizontal.

(*b*) Because an alternating-current lamp, by itself, throws a large amount of light above the horizontal, where it is of little or no use. See Arts. **20** and **23.**

ELECTRIC LIGHTING.

(PART 4.)

---

(1) To operate circuit *1'* on machine A, insert plugs at b_{10}–c_{10}–b_6–c_6–b_2–c_2. To operate circuits *2'* and *3'* in series on machine C, insert plugs at f_{10}–f_9–d_9–d_6–d_2–e_2–e_3–f_3–f_2–g_2–g_6–g_{10}.

(2) A diagram similar to Fig. 6 is required.

(3) By disconnecting the ends of the faulty coil from the commutator, tying them back out of the way, and connecting the segments by means of a "jumper." See Art. **37.**

(4) (*a*) Those with open-coil armatures and those with closed-coil armatures.

(*b*) The Brush and Thomson-Houston machines belong to the first class, and the Wood or Fort Wayne, Western Electric, Excelsior, and Ball belong to the second. See Art. **15.**

(5) See Art. **69.**

(6) By connecting one side of the voltmeter to the line and the other to the ground, as indicated in Fig. 3. See Art. **4.**

(7) See Arts. **25** and **26.**

(8) The new machine is of the multipolar type and is of considerably larger capacity than the old style. It requires no wall controller, but is provided with a controller on the machine itself. See Arts. **22** and **23.**

(9) See that the current always flows through the circuits in the proper direction. Never open a circuit when the current is on. If the circuit must be cut out, first short-circuit its terminals. See Arts. **53** and **55.**

(10) In order to keep the current at a constant value. Arc machines are series-wound, and if no regulator were provided, the current would increase as lamps were cut out and decrease as they were cut in. See Art. **14.**

(11) Plug from $A+$ to $1+$, and from $A-$ to $1-$. Plug $B+$ to $3+$, $3-$ to $4+$ by means of cable J, and $4-$ to $B-$.

(12) Constant potential, because the same alternators can then be used for both arc and incandescent lighting. See Arts. **13** and **42.**

(13) The flashing occurs at regular intervals. See Art. **20.**

(14) See Art. **47.**

(15) $\frac{3}{16}$ to $\frac{1}{4}$ inch. See Art. **20.**

(16) They may be operated directly from the alternator by providing each lamp with a choke coil that is cut into circuit in case the lamp goes out. They may also be operated by using a transformer with an adjustable secondary, by using a constant-current transformer, or by inserting a reactance in the circuit, this reactance being arranged so that it varies with changes in the load in such a way as to keep the current constant. See Arts. **43** to **50.**

(17) Improper setting of brushes, defective air blast, overload on machine, speed too low, cross on line, break in shunt circuit of lamps. See Art. **20.**

(18) The break is located by first grounding both ends of the circuit at the station. The circuit is then opened about its middle point and each side rung up, in turn, by connecting one terminal of the magneto to the line and the other to the ground. After determining which side the break is in, the circuit is completed at this point and the lineman moves on to another point about half way between

the station and the last point tested. In this way the stretch of circuit in which the break is known to exist is narrowed down to within small limits. See Art. **2.**

(19) See Art. **40.**

(20) Inaccurate setting of brushes, defects in air jets, dirty commutator, too much oil on commutator, too large current, ragged or bent brushes. See Art. **21.**

(21) See Art. **39.**

(22) To improve the regulation when the machine is operated on a number of lamps considerably less than its normal capacity. See Art. **16.**

(23) The circuit ends are left open at the station, and the different parts of the line are rung up for grounds, by opening the circuit and connecting one terminal of the magneto to the line and the other to the ground. See Art. **3.**

(24) Because the coil will overheat on account of the local currents set up in it, and this overheating might injure the adjacent coils. See Art. **37.**

INDEX

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Brush arc lamp 18 44" means that Brush arc lamp will be found on page 44 of section 18.